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Fusion of Information from Optical, Thermal, Multispectral Imagery and Geologic/Topographic Products to Detect Underground Detonations

Carroll L. Lucas, Matthew Heric, James M. Newlin, and David R. Van Horne

Autometric, Incorporated
5301 Shawnee Road
Alexandria, Virginia 22312-2312

12 February 1992

Phase II SBIR Annex 1 - Ground Truth Report

Prepared for:

U.S. Army Missile Command
AMSMI-PC-BFA/DARPA Project Office
Redstone Arsenal, AL 35898

Defense Advanced Research Projects Agency
Building 7770, Room 107/Charles Piner
AMSMI-RD-DP-TT
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This report documents the results of a Small Business Innovative Research (SBIR-Phase II) project conducted for DARPA focusing on the use of all-source overhead remote sensor imagery for monitoring underground nuclear tests and related activities. This documentation includes: 1) the main unclassified body of the report; 2) a separate ground truth Annex; and 3) a separate classified Annex. Autometric's approach was to investigate the exploitation potential of the various sensors, especially the fusion of products from them in combination with each other and other available collateral data. This approach featured empirical analyses of multisensor/multispectral imagery and collateral data collected before, during, and after an actual underground nuclear test (named "BEXAR"). Advanced softcopy digital image processing and hardcopy image interpretation techniques were investigated for the research. These included multispectral (Landsat, SPOT), hyperspectral, and subpixel analyses;

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19. stereoscopic and monoscopic information extraction; multisensor fusion processes; end-to-end exploitation workstation concept development; and innovative change detection methodologies. Conclusions and recommendations for further R&D and operational uses were provided: 1) the general areas of sensor capabilities, database management, collection management, and data processing, exploitation, and fusion; and 2) specific multispectral, hyperspectral, subpixel, three-dimensional modeling, and unique unconventional imaging sensor technology areas.

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SECTION I
INTRODUCTION

Autometric is currently conducting research for the DARPA under the aegis of a Small Business Innovative Research (SBIR), project entitled "Fusion of Information from Optical, Thermal, Imagery and Geologic/Topographic Products to Detect Underground Detonations." Phase-1 of the study established the feasibility of using such data to support the detection and monitoring of underground tests. The second phase of the study builds upon the results of Phase-1 and brings the analyses into the real world by testing the feasibility against a real underground test, recommends the suite of sensors to be used and the tools to exploit them.

Autometric is now conducting Task One of Phase-2 which involves the selection of an ongoing underground nuclear test, the scheduling of overhead imagery and the analysis of both the collected imagery and collateral data. A significant portion of this task is the compilation of a Ground Truth document that provides an historical background of the test and the changes that occurred.

This report provides data that can and will be used to support the development of special digital tools that may be employed with multispectral data collected by various civil sensors. Documentation of ground truth before and after the test detonation, provides data on the visible changes that have occurred which should become the focal point for developing analytical tools to record the existence of an underground test.

1.0 BACKGROUND

After the successful fruition of Phase-1 of this SBIR, plans for Phase-2 were developed to establish the practical aspects for detecting and monitoring deep underground tests, worldwide. The necessary contacts were made with the Department of Energy (DOE), the Nevada Test Site (NTS), the National Photographic Interpretation Center (NPIC), and other Government organizations involved in nuclear testing at the NTS. A pending underground nuclear test at the NTS, code named BEXAR, was selected and permission to participate was acquired, provided that the new tasks did not interfere with the original test plan or schedule.

A parallel test plan was produced that included collating all the collateral data that was available on the site area, the collection of historical aircraft and satellite imagery, and the tasking of new imagery resources to collect data shortly before and after the test date. Among the imaging systems that were tasked were the Landsat Thematic Mapper (TM), and a MTL Inc. sixty-three band hyperspectral* sensor flown in an Aztec aircraft. Calendar years 1988 and 1989 imagery from the French SPOT satellite multispectral system was already available inhouse. The Defense Mapping Agency (DMA), Point Positioning Data Base (PPDB) material was also made available.

In March, 1991, final preparations were made to acquire ground truth before and after the test date. Autometric personnel were at the test site and coordination meetings were held with other participating organizations. On 4 April, 1991, after two short delays, the underground test was successfully culminated.

* Although the community is trying to standardize the number of bands that a hyperspectral sensor must collect as 100 or above, for the purpose of this study, hyperspectral will be used for sensors that collect more bands than the LANDSAT Thematic Mapper.

2.0 TARGET LOCATION AND DESCRIPTION

The BEXAR site is in the northwesternmost quadrant of the NTS, at the top of a mesa which rises to an altitude of approximately seven thousand feet above sea level (Figure I-1, I-2). The mesa is bounded on the north by a terrain feature called Dead Horse Flat, and on the west and south by Silent Canyon. Geologic collateral data indicates that the mesa is comprised of rhyolitic ash flow tuff underlain by quartz latite ash flow and mafic/rhyolite tuff to a depth of over six hundred meters (Figure I-2a).

Vegetation in the area is sparse, consisting primarily of stunted cedar and other evergreen trees/bushes. Small patches of snow and ice were observed on the north sides of slopes and clumps of vegetation.

BEXAR ground scars designating site activity and road building were not evident on the early historical imagery collected by the French SPOT sensor in 1988, indicating that the site is new and uncontaminated by previous tests. However, initial scarring can be detected on the 1989 imagery. A few kilometers away, three other historical abandoned sites appear to have a similar configuration as the completed BEXAR site, indicating that a series of related tests may be underway (Figure I-3). September, 1983 NHAP coverage over the historical sites show no ground scars (Figure I-4). The size difference between the three site scars also indicates that BEXAR is the largest and/or most sophisticated of the tests.

The BEXAR site is configured as a truncated triangle oriented with its truncated point to the north-northeast of the site. A small square area can also be observed attached to the Easternmost leg of the triangular scar. The site has been cleared of vegetation, bulldozed, and scraped to produce a level surface, and appears to have been periodically sprayed with water and rolled to reduce dust. Two bermed artificial ponds built along the northwesternmost edge of the site scar, contain a small amount of water, rimmed with ice. A continuous circular scar, approximately 300 meters in radius, with the GZ as its center, can be observed on overhead imagery (Figure I-5).

This is a defoliated trail containing radiological instrumentation as well as a single fence line used as a security measure to keep animals off the site and to alert personnel that they are approaching a sensitive area.

Figure I-1 Location Map

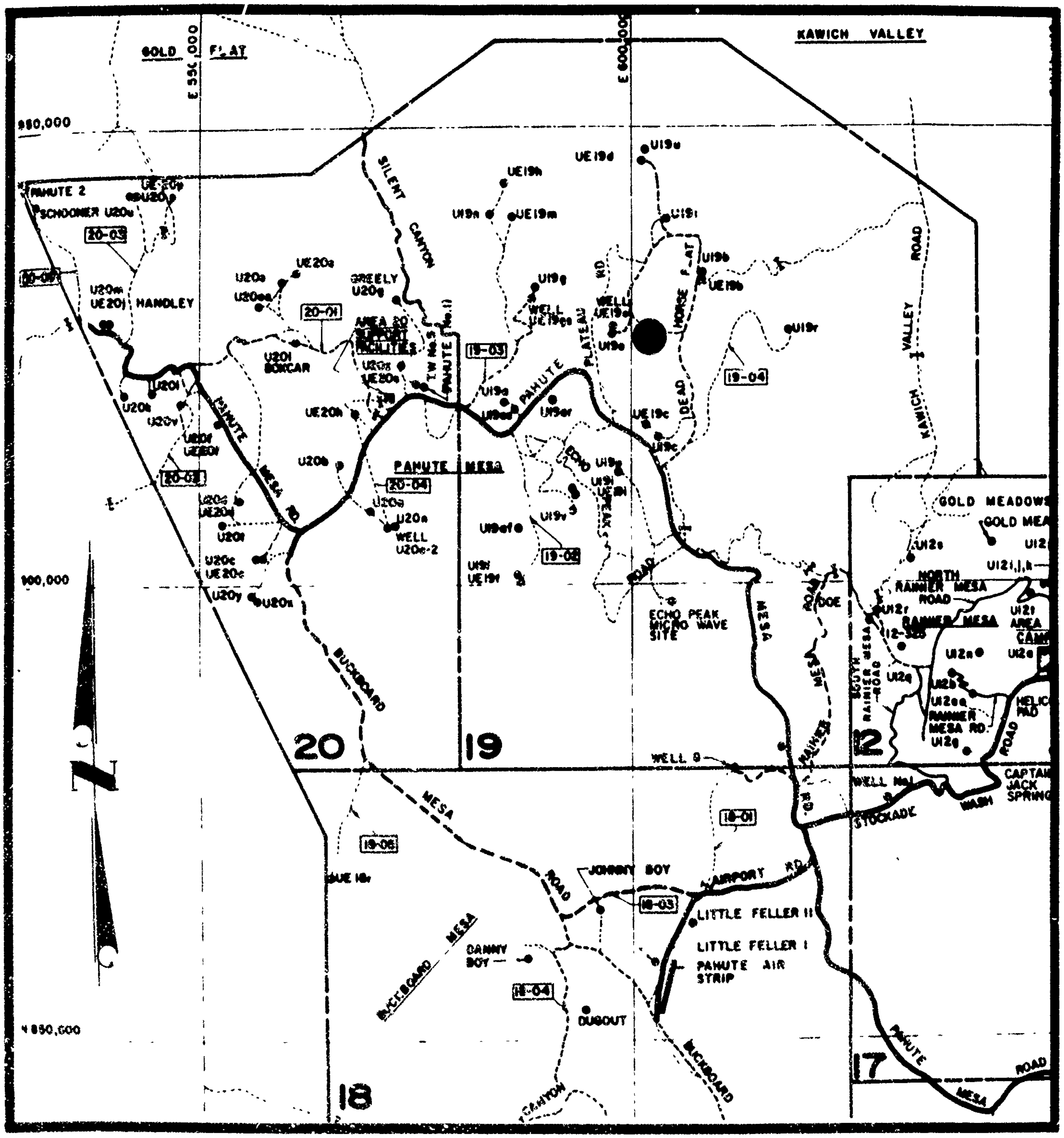


Figure 1-2. Map of [illegible] Test Site (NTS)

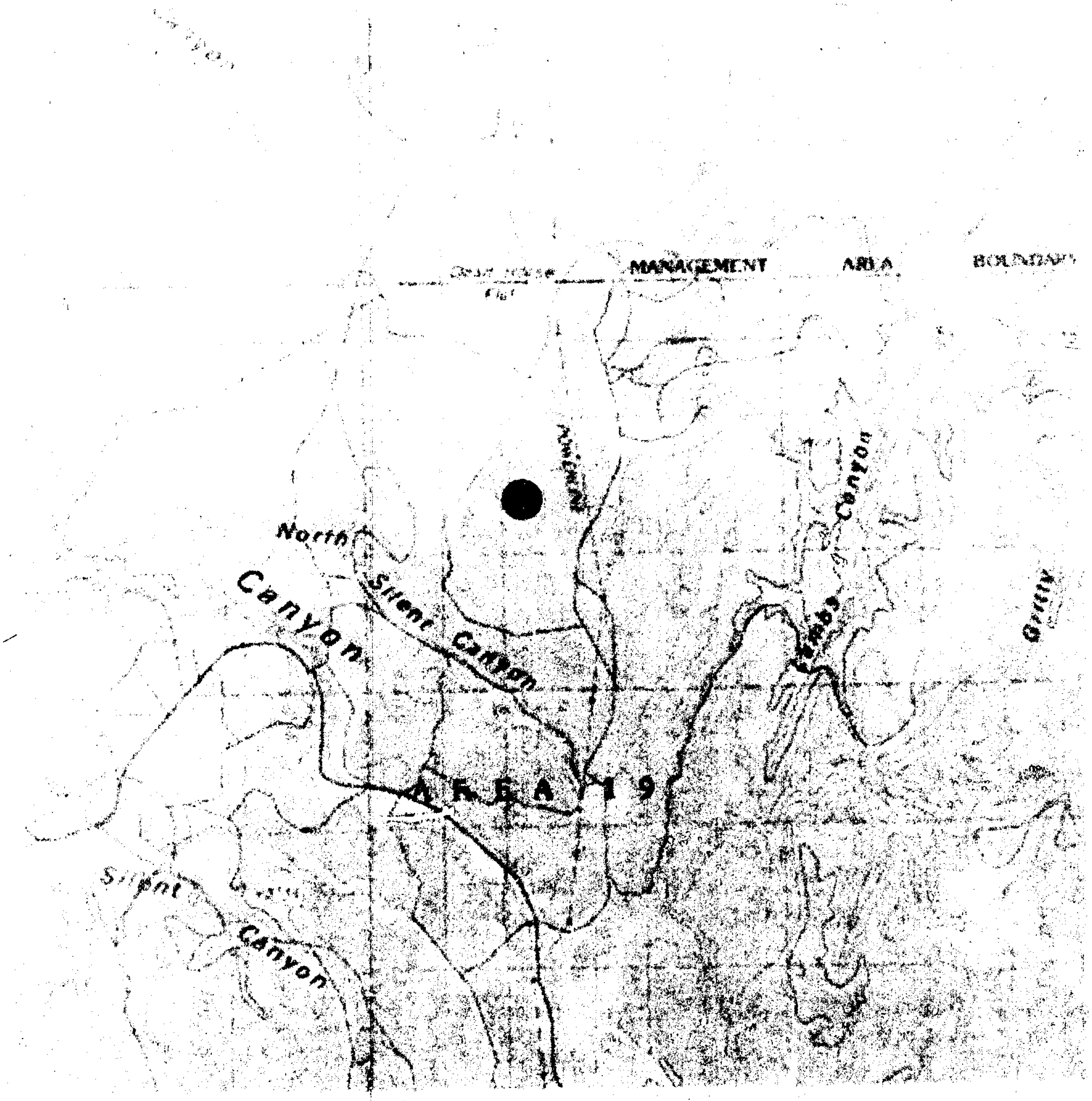


Figure I-2a Geologic Map of BEXAR

Ammonia Tanks Member—Rhyolitic to quartz latitic ash-flow tuff. In areas distal from Timber Mountain, compound, nonwelded to densely welded, in part devitrified, maximum thickness 170 m. On Timber Mountain dome, locally subdivided into intracaldera:

Rainier Mesa Member—Compound cooling unit, nonwelded to densely welded high-silica rhyolite with caprock of quartz latitic ash-flow tuff, generally devitrified center and vitric top and bottom; generally less than 150 m thick, except near west wall of Timber Mountain caldera (Transvaal Hills) where thickness exceeds 350 m

Ttt **Trail Ridge Member**—Multiple-flow simple cooling unit of comenditic rhyolite ash-flow tuff with thin ash-fall pumice lapilli and local pebbly tuffaceous sandstone at base; as much as 80 m thick

Pahute Mesa and Rocket Wash Members—Composite ash-flow tuff sheet of high-silica sodium-rich rhyolite comprising four cooling units that locally coalesce to a single or compound cooling unit; as much as 180 m thick. Includes a thin bedded ash-flow and ash-fall pumice lapilli base

QTac **Alluvium and colluvium (Holocene, Pleistocene, Pliocene, and Miocene)**—Unconsolidated to moderately cemented, locally deformed, alluvial fan, flood plain, stream bed, talus, slope wash, and eolian deposits; thickness variable, as much as 600 m thick

Figure I-3 SPOT Coverage of the NTS

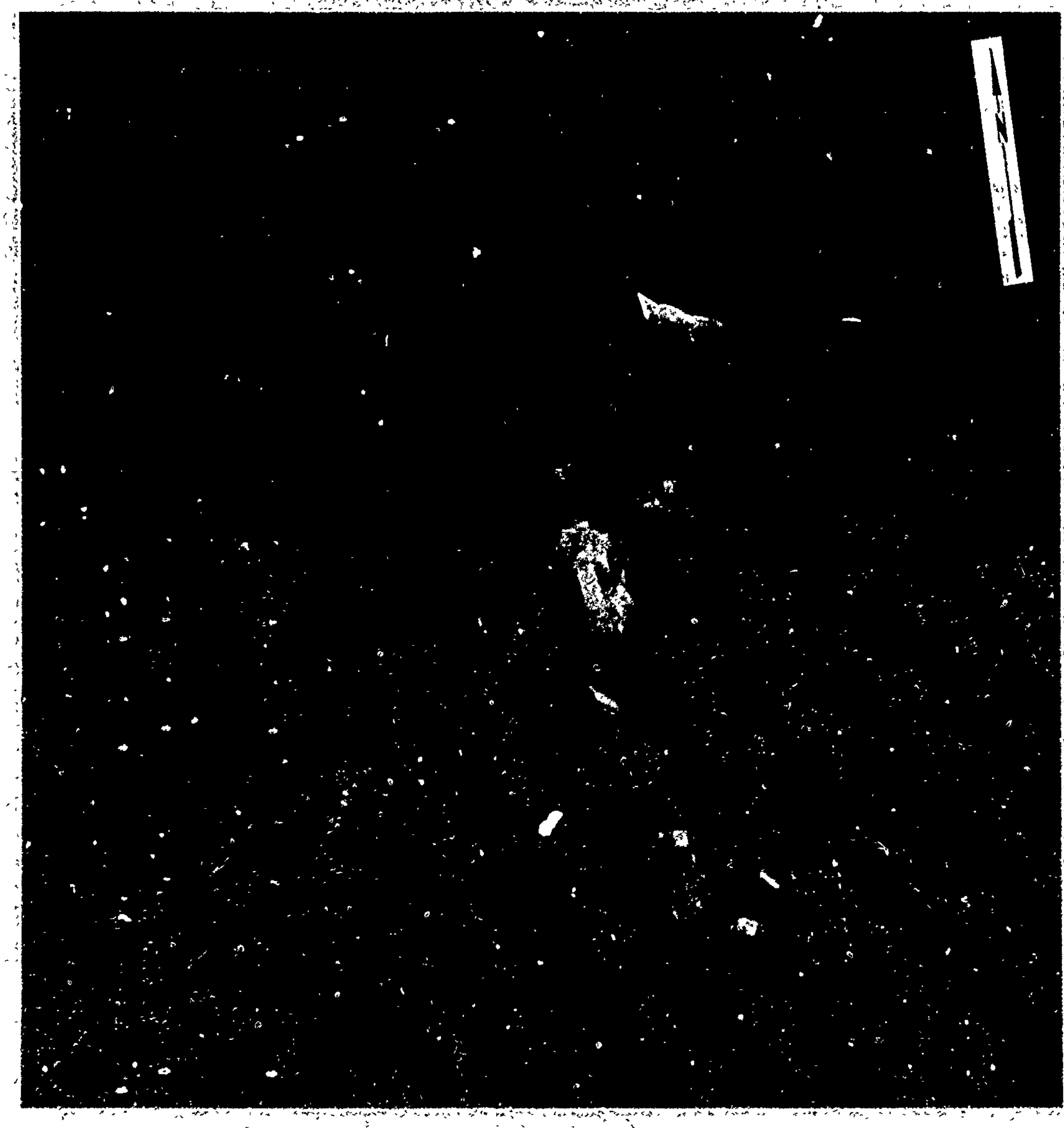
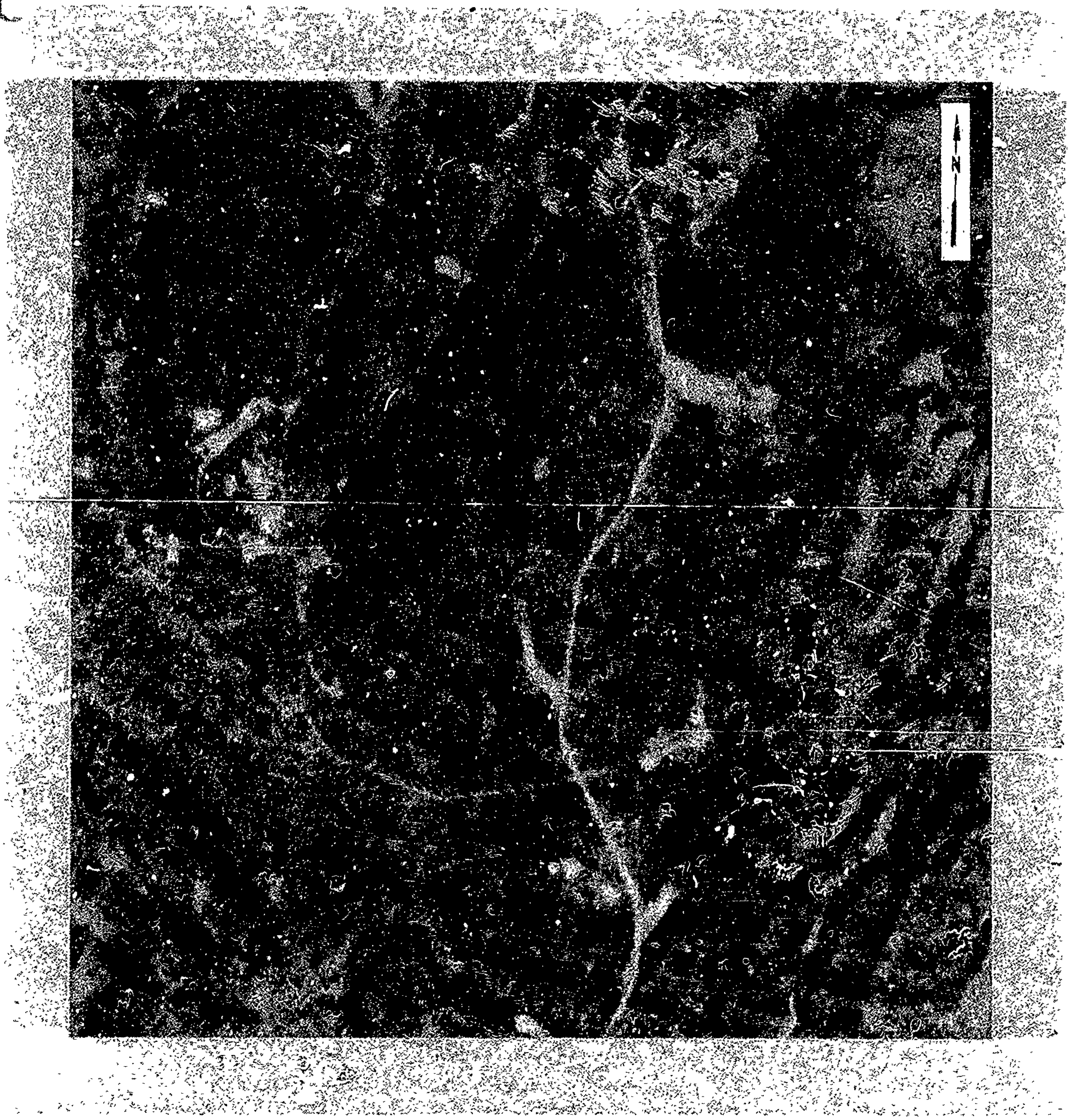
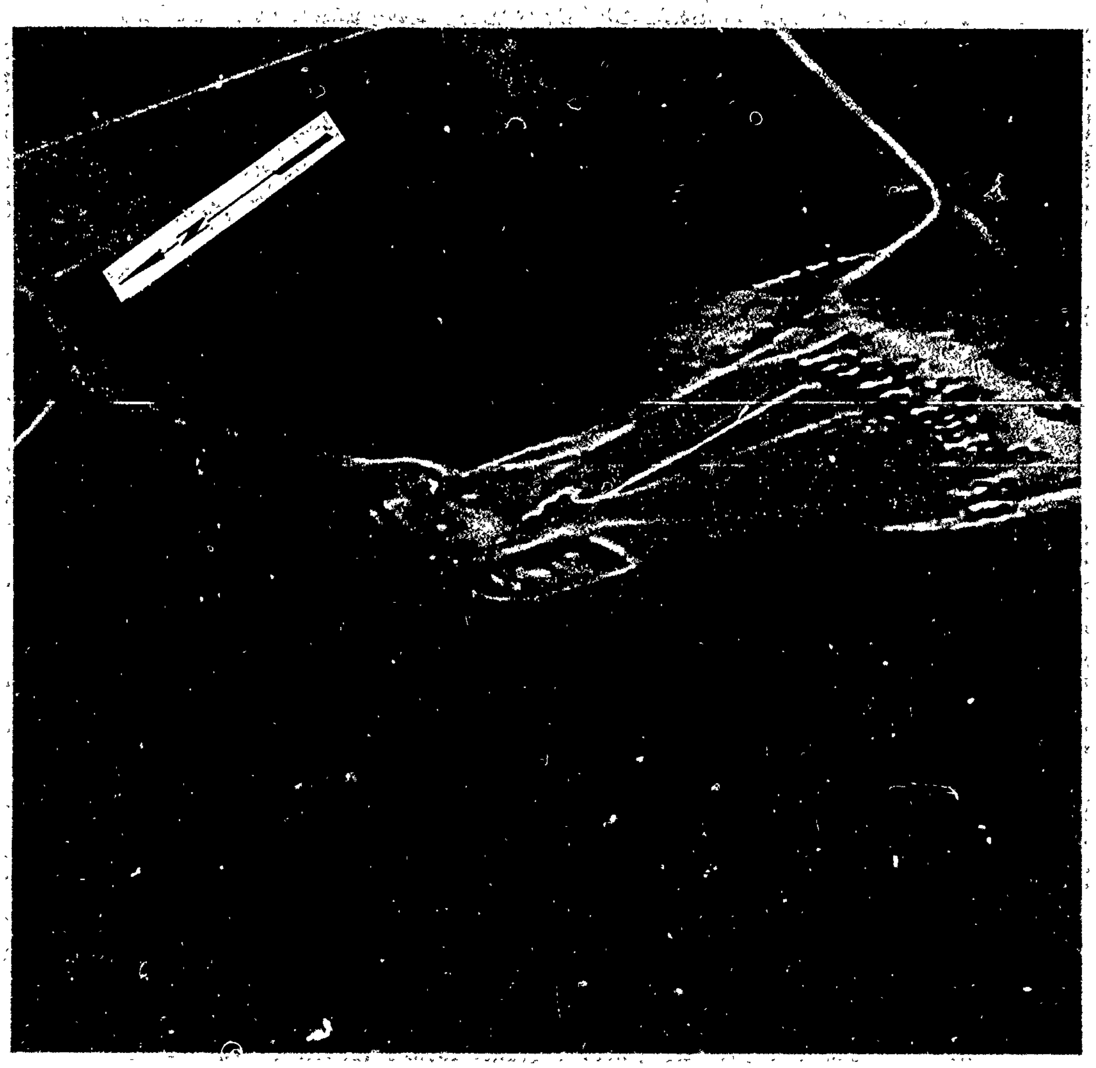


Figure I-4 Aerial (NHAP) Overview of Test Site



Oriented in a straight line along the southern base of the BEXAR site are ten large metal trailers, a metal two story temporary building and five other small trailer configurations. These trailers/buildings are referred to in this report as Instrumentation Site-1 through Instrumentation Site-4. Clustered in the rear of each trailer are collections of auxiliary equipment such as air conditioners, humidifiers, generators, etc. as well as personnel vehicles and an occasional piece of heavy equipment, depending on the activity level of the ongoing test. Emanating from the northern ends of the trailers are large cable bundles which converge just to the south of the GZ, forming one large looping bundle that terminates at the GZ (Figure I-5).

Figure I-5 Aerial Video Overhead Coverage of BEXAR



3.0 GROUND TRUTH OBJECTIVE AND CHRONOLOGY

The objective for collecting Ground Truth before and after test Time Zero (TZ), is to document in detail the conditions of the area in order to support comparative analyses of scheduled overhead imagery collections. Through such research, new analytical tools can be tested against known conditions to determine their reliability and viability.

On 1 April, 1991, Autometric personnel were at the BEXAR test site to plan for aircraft hyperspectral collections over the GZ, shortly before and after TZ. The aircraft used was the twin engine Piper Aztec (Figure I-6) which carries the MTL Systems Inc. sixty three band ASIS* hyperspectral sensor, and a video camera. Two altitudes were selected for two similar flight lines over the GZ both before and after TZ. This would allow the analysis of pixel size restrictions on test monitoring. The NTS also planned a helicopter flight that would monitor the test with a video camera throughout the test duration. Further, they had installed two automatic ground cameras, boresighted to cover the GZ from remote terrain sites.

On 2 April, Autometric personnel collected ground photographs of the GZ and its surrounds, concentrating on the equipment configuration and on the surface of the terrain. The TZ was delayed twenty-four hours due to weather restrictions, the new TZ was set for 0900 hours local time, on 4 April. On 3 April, the MTL aircraft collected its first data over GZ. Although the video camera failed, excellent hyperspectral coverage was collected at two different altitudes. On 4 April, the TZ was delayed an additional two hours because of unfavorable wind conditions, however the test was successfully detonated at 1100 hours local time. Figure I-7, is a representative sample of the winds aloft data that was collected throughout the test period. At 1400 hours, the MTL aircraft collected low altitude hyperspectral coverage of the site, but was not able to acquire high altitude data due to cloud cover. Although attempts were made to get high altitude coverage for several days after the test, the weather never allowed for a successful collection. On 5 April, the Autometric personnel collected additional ground photography of the GZ and its surrounds, so that comparisons could be documented and correlated with anticipated changes that may be detected by overhead multispectral, hyperspectral and multiple sensor products.

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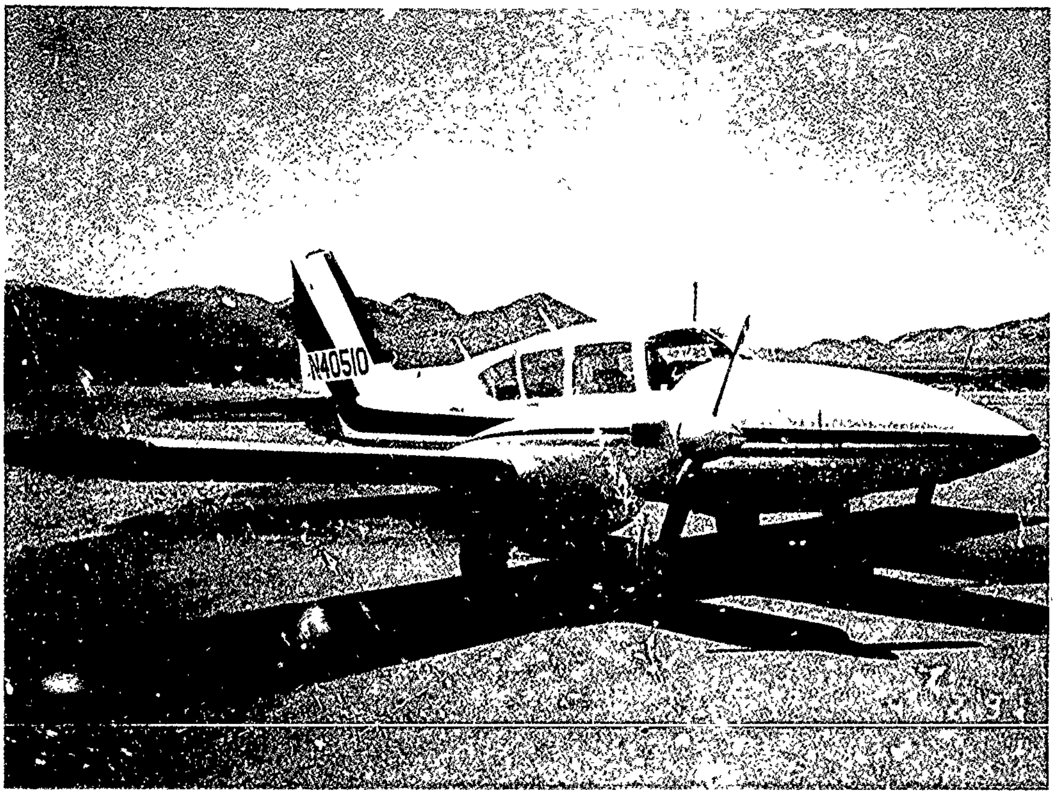
* Airborne Spectroradiometric Imaging System (ASIS)

Figure I-6 MTL PIPER AZTEC with 63 Band Sensor



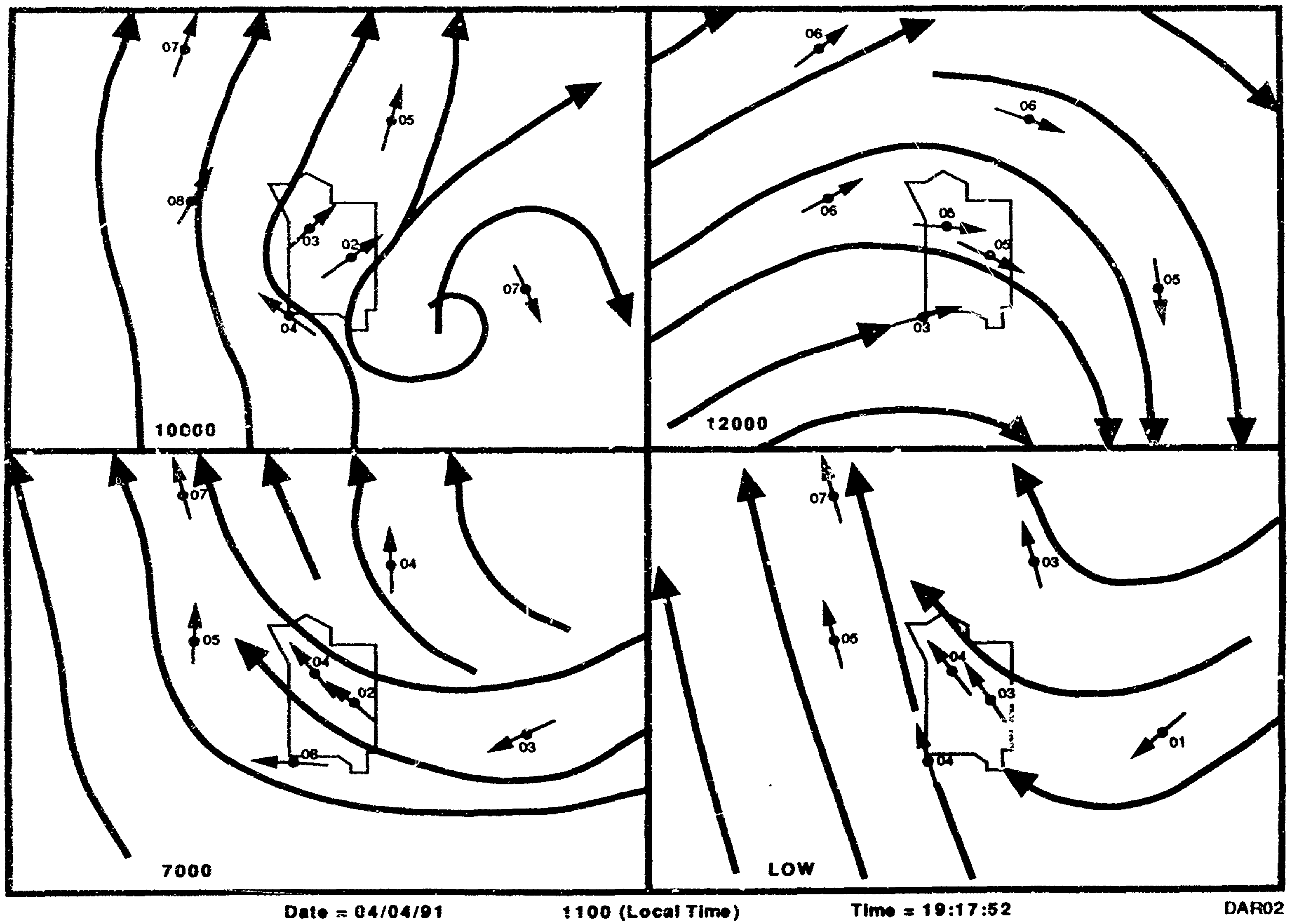


Figure I-7 Winds Aloft Chart

SECTION 2

GROUND TRUTH DATA ANALYSIS

1.0 PRE-DETONATION

Using the previously collected geological and topographical maps, as well as historical imagery as a database, the team acquired additional field data by visiting the site prior to and after detonation and taking ground photography of the operations. Following are descriptions and analyses of individual images from both the ground photography and the helicopter video camera imagery provided by the Test Directorate.

Figure II-1a Drawing of BEXAR

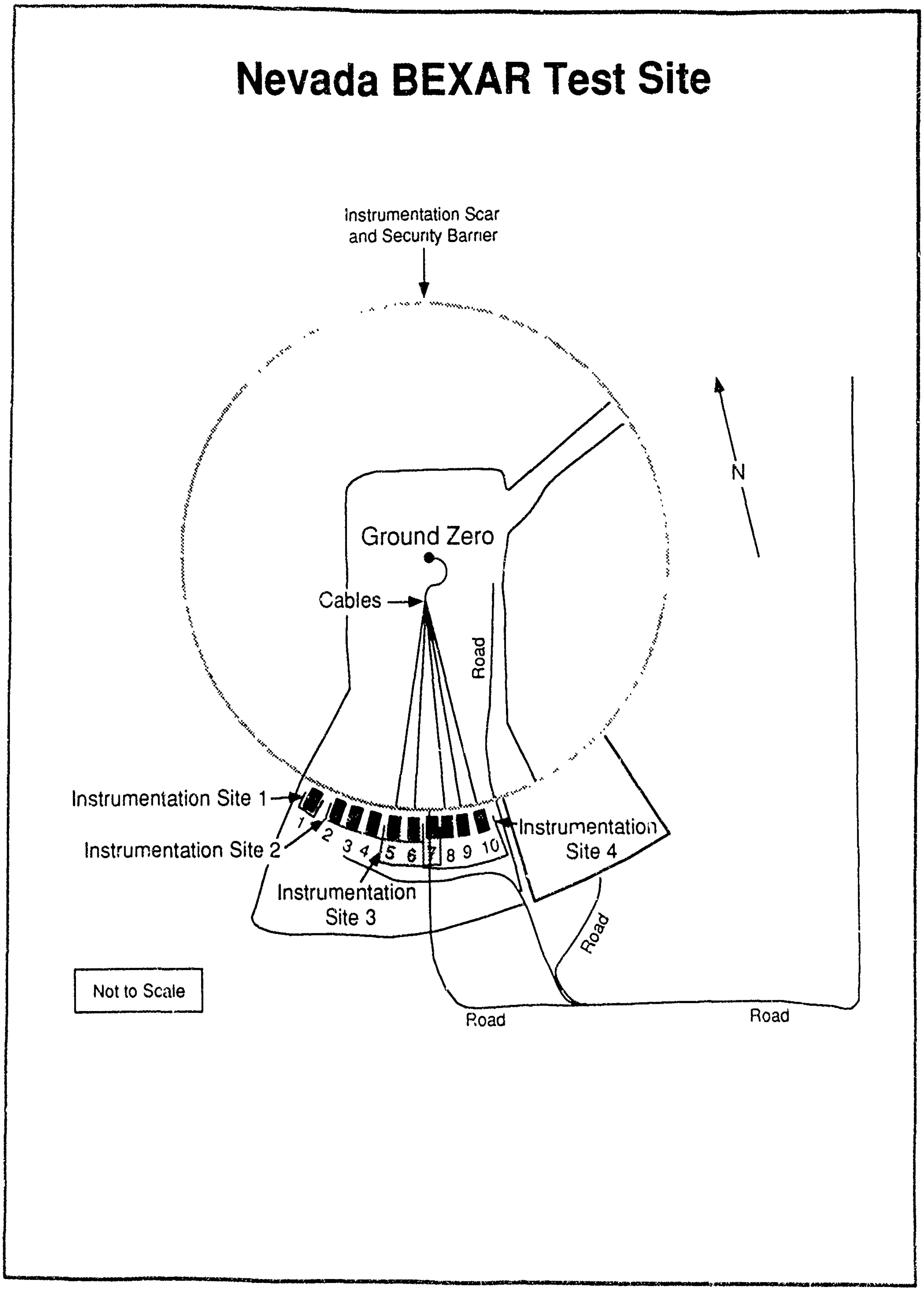


Figure II-1 AERIAL VIDEO OVERVIEW FROM HELICOPTER OF TEST SITE

This image has been "grabbed" from the videotape collected by helicopter shortly before the scheduled test detonation. Helicopter coverage had been arranged by the Test Directorate to document aboveground conditions slightly before, during and after the detonation, and a copy of the tape was provided to Autometric to support their analyses.

The image provides full coverage of a typical ground scar produced by the preparations for an underground test. The nearly north/south orientation of the scar was probably selected to accommodate the use of the prevailing winds to reduce potential contamination of the diagnostic trailers, and the nearest habitation, should venting occur. The test area has been cleared of vegetation, leveled, and the surface appears to have been treated to reduce wind blown dust problems. The scar appears as an isolated truncated pyramid, surrounded by sparse evergreen vegetation. A broad unsurfaced road with wide radius turns can be observed entering the extreme southeastern end of the test area. A square area has also been cleared adjacent to the eastern edge of the test site. This area was probably used as temporary storage, and to assist in the final positioning of the diagnostic trailers and their auxiliary equipment along the southernmost boundary of the site. Two bermed artificial ponds have been constructed at the north-northwestern end of the test site and now contain a small amount of water. Large white bundles of above-ground cables originate from several of the trailers and converge to a point just southwest of the GZ where they form a single cable that snakes to the GZ. A portion of a circular scar in which the GZ is the center, can be observed along the southeastern edge of the test area.

The complete lack of activity, vehicular traffic, and extraneous equipment is indicative of an imminent detonation.

Figure II-1

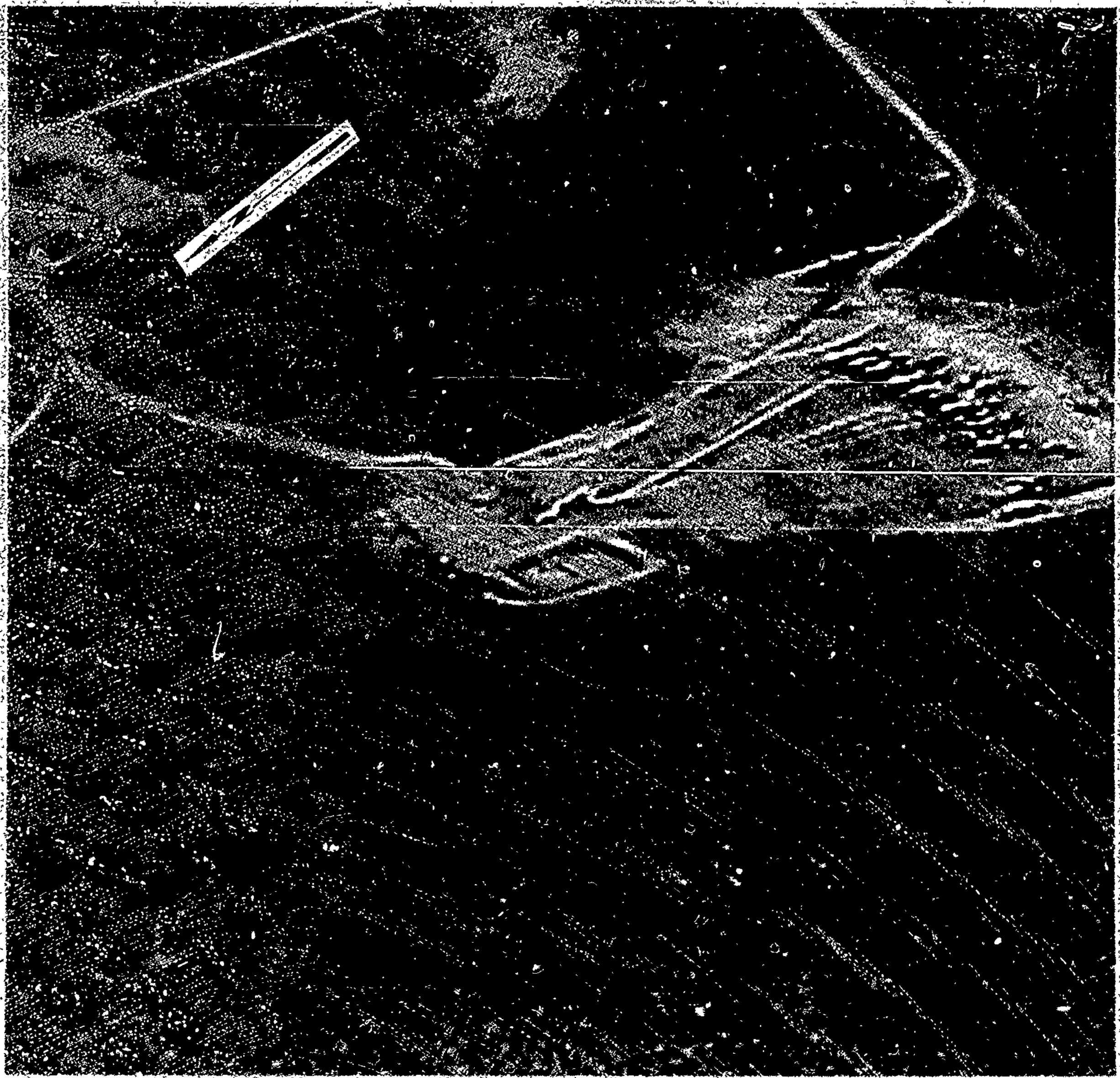


Figure II-2 AERIAL VIDEO OF INSTRUMENTATION VAN SITE-1

In order to better describe individual components along the line of diagnostic equipment at the southern edge of the test site, they have been arbitrarily clumped into 4 "instrumentation sites," beginning at the extreme southwestern edge of the site.

Instrumentation Site-1 is comprised of a total of four closed structures and two unprotected equipment clusters. All six structures appear to be elevated upon platforms and all appear to be connected by above ground white cable bundles. The structure at the southwesternmost end of the line of equipment is a large white painted metal van with small windows and two small square auxiliary structures attached to the southern end of the van by cables. An unsurfaced perimeter road parallels the western edge of the van. To the east of the van, are three structures, a small square unit with ducting on its roof, a rectangular unit (small van) aligned to the south of the first unit, and a smaller square open structure containing equipment oriented along the same axis as the other two structures. To the east of the last structure is another square unit similar to the one mentioned above with the exception that a ventilator has taken the place of the ducting. Behind this structure is a raised platform containing equipment. All appear connected to each other by above ground cables. Cables from the large van and the square ducted structure combine and are connected to a cable bundle that goes toward the other instrumentation sites rather than directly to the GZ. A perimeter fence passes directly to the north of the site, separating it from the GZ area. Aside from a few vehicle tracks, the surface of the terrain is smooth and appears treated to keep the dust to a minimum.

Figure II-2

Figure II-3 AERIAL VIDEO OF INSTRUMENTATION VAN SITE-2

Within this image, Instrumentation Site-2, are five long diagnostic trailers, each connected to the GZ by aboveground fiberglass cable bundles. Interspersed among them are seven square, flat roofed buildings, each containing obvious roof vents. Two small rectangular trailers are also deployed in tandem, facing the GZ. Three square and one rectangular open instrument areas can be observed to the rear of the trailers. Centered approximately midway along the line of trailers is a large, metal, two-story temporary building with a metal, peaked roof. The building is also connected to the GZ by above-ground cable bundles. The ground surface around and in front of the trailers has been scraped flat, and all building and instrumentation sites appear to be slightly raised above the surface. A single fence line traverses in front of the trailers, separating them from the GZ area.

Figure II-3

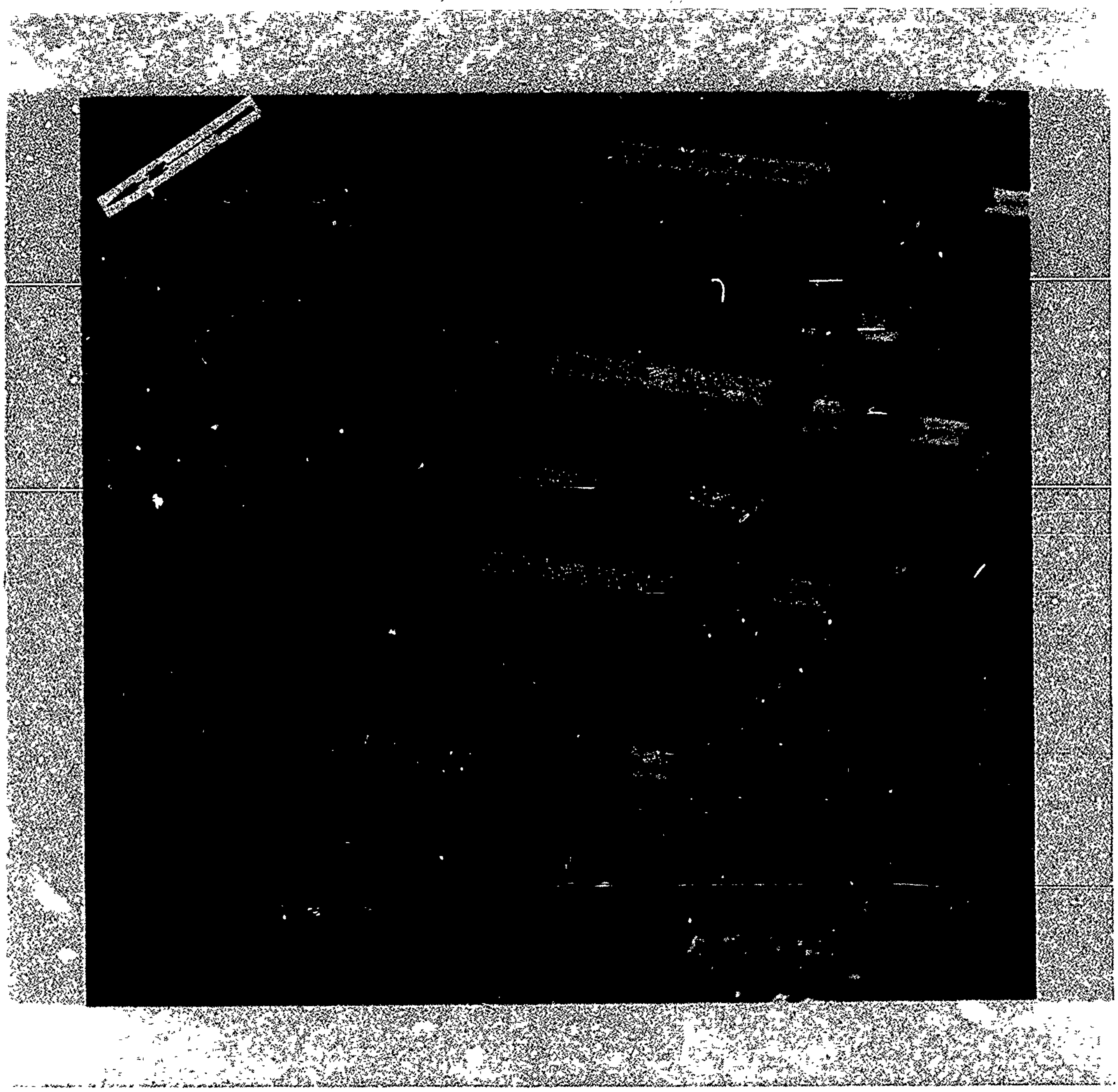


Figure II-4 AERIAL VIDEO OF INSTRUMENTATION VAN- SITE-3

This image, Instrumentation Site-3, was acquired from the south of the trailers, looking towards the north to GZ. It provides considerable detail about the main temporary metal building, its three small square, covered peripheral buildings and three of the large diagnostic trailers with their support buildings and open instrumentation sites. The surface of the ground shows some trackage but appears flat and treated to inhibit dust. A fence line separates the trailers from the GZ area.

Figure II-4

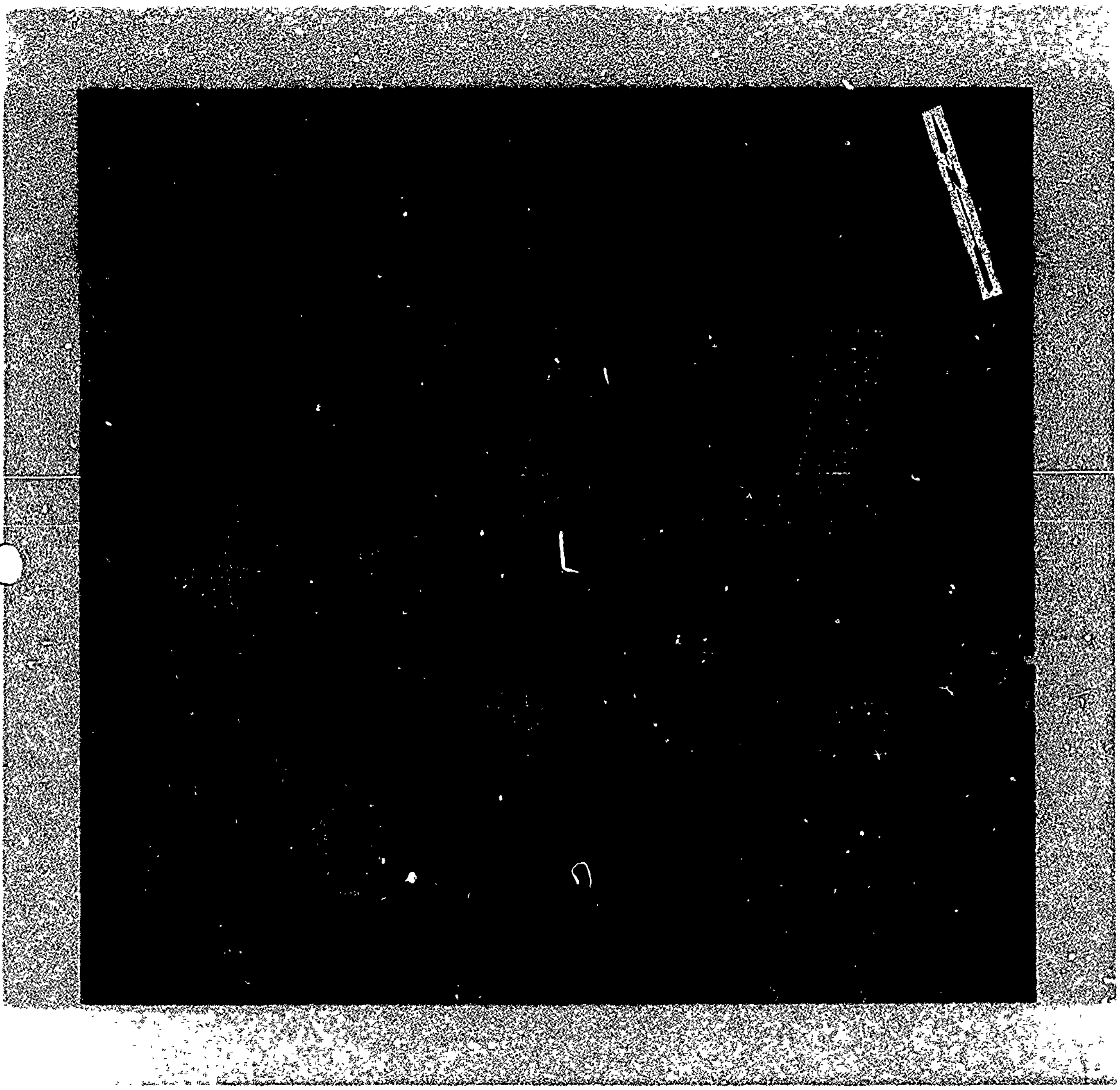


Figure II-5 AERIAL VIDEO OF INSTRUMENTATION VAN SITE 4

This image depicts the last four trailers in line of instrumentation vans at the southern end of the test site. The westernmost van also appears in Figure II-4. Of the last three trailers, the middle one is the focus for the largest bundle of cables emanating from the vans to the GZ. Each trailer has its own smaller vented building in line with and south of the trailer. Three open instrumentation sites are also in place to the south of the second and third trailers. Paired large air conditioning units are attached to the last two trailers, and an additional unit is connected to the third trailer. There is no indication of personnel activity, vehicles or equipment.

Figure II-5

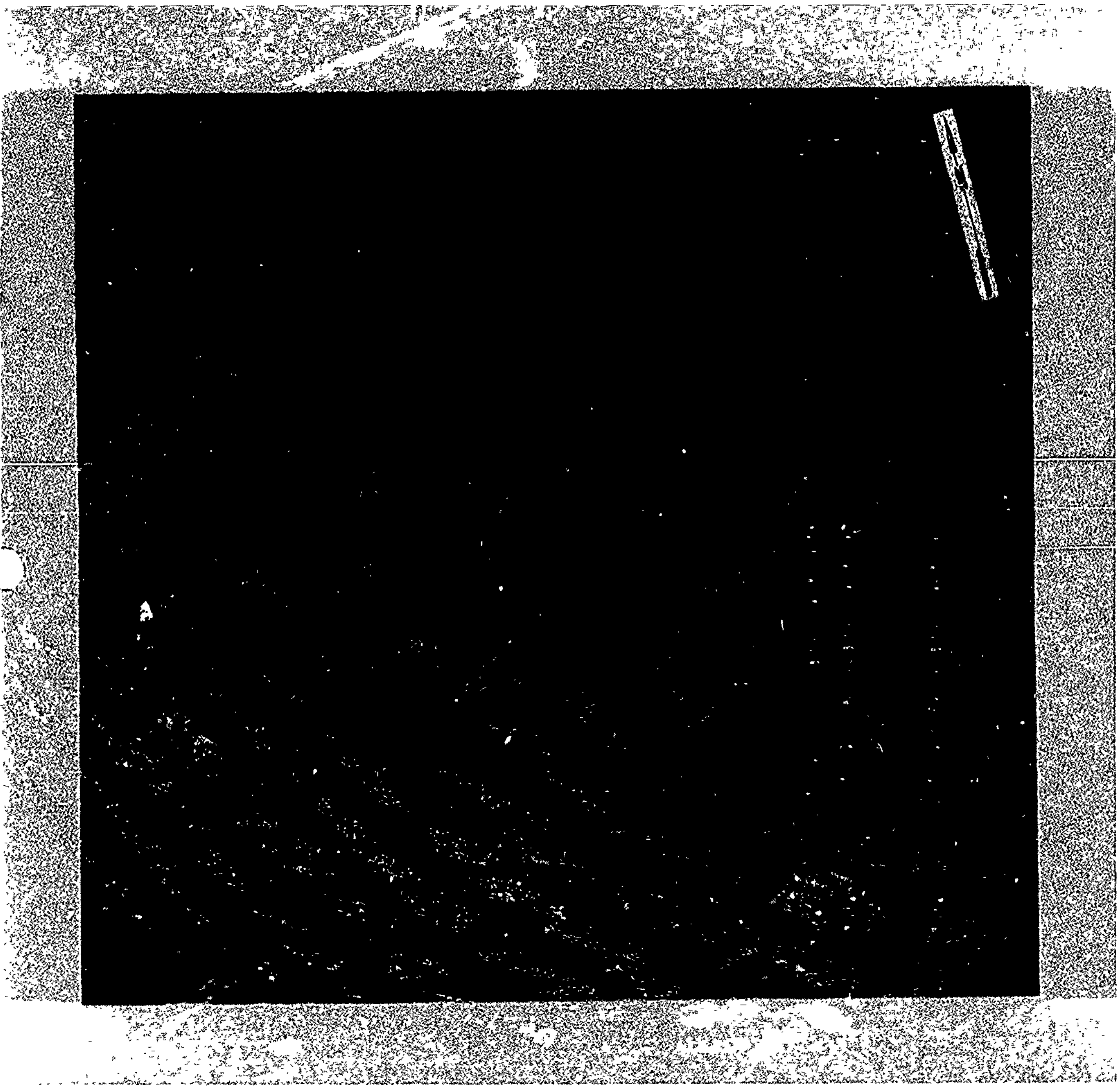


FIGURE II-6 GROUND PANORAMIC (360°) FROM THE INSTRUMENTATION AREA, PRE-DETONATION

This series of ground photographs was taken one day before the scheduled test. The position is in the open area between the westernmost cluster of trailers and the continuation of the line. The pan begins looking at the GZ to the north, then west to the edge of the trailer line, and along the trailer line looking to the east. The GZ can barely be discerned as a white target board near the center of the large bulldozed flat area.

To the south and west of the GZ is a small square mobile trailer containing a small dish antenna and a video camera. A mobile generator is also parked adjacent to the trailer. This equipment was moved shortly after these photos were taken and do not show up in the helicopter images.

To the west of the photographers position is a cluster of trailers with SIMULATOR-3 in the foreground. Since these images will be compared to post detonation images, note particularly the condition of the soil around the trailers, the absorbing foundation pillars protecting SIMULATOR-3, and the small collection of rocks in the foreground. Note also that each trailer and open equipment platform is mounted several feet above ground level.

Looking toward the southeast, several of the other trailers are observed. Note all the vehicular traffic and the position of the tall crane. Note also the upright red and white vehicle barrier protecting a line of cables.

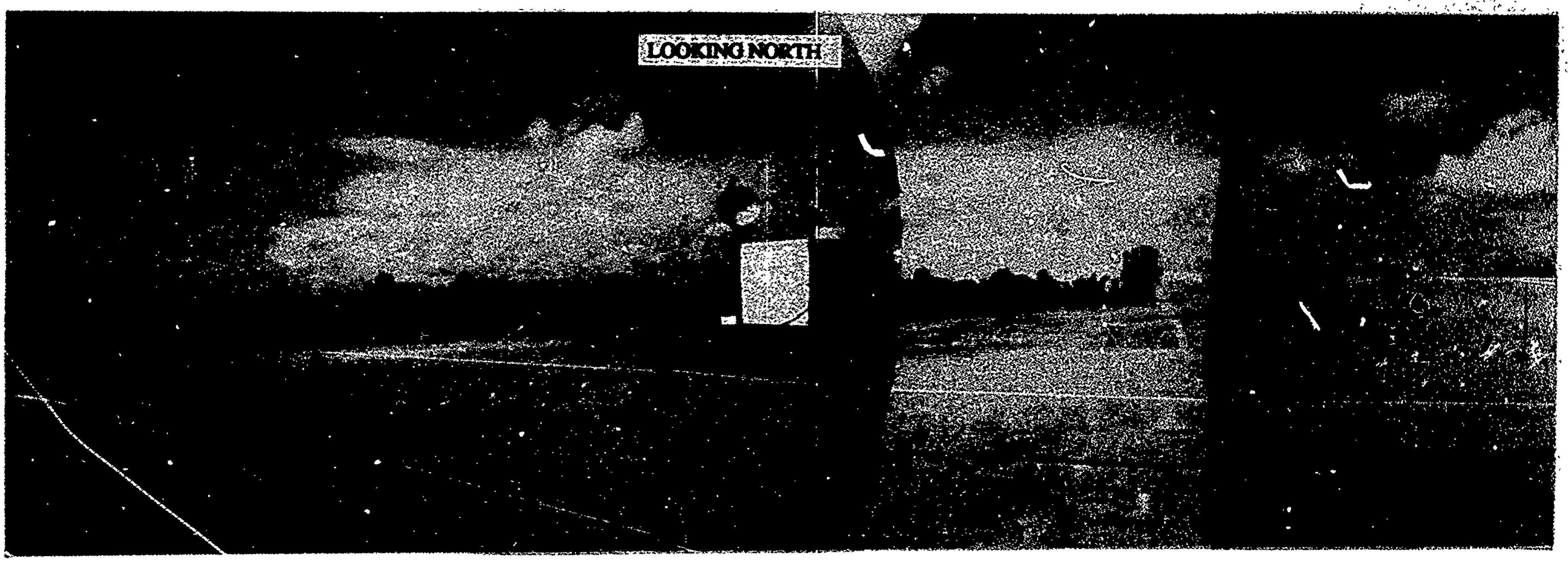


Figure II-6

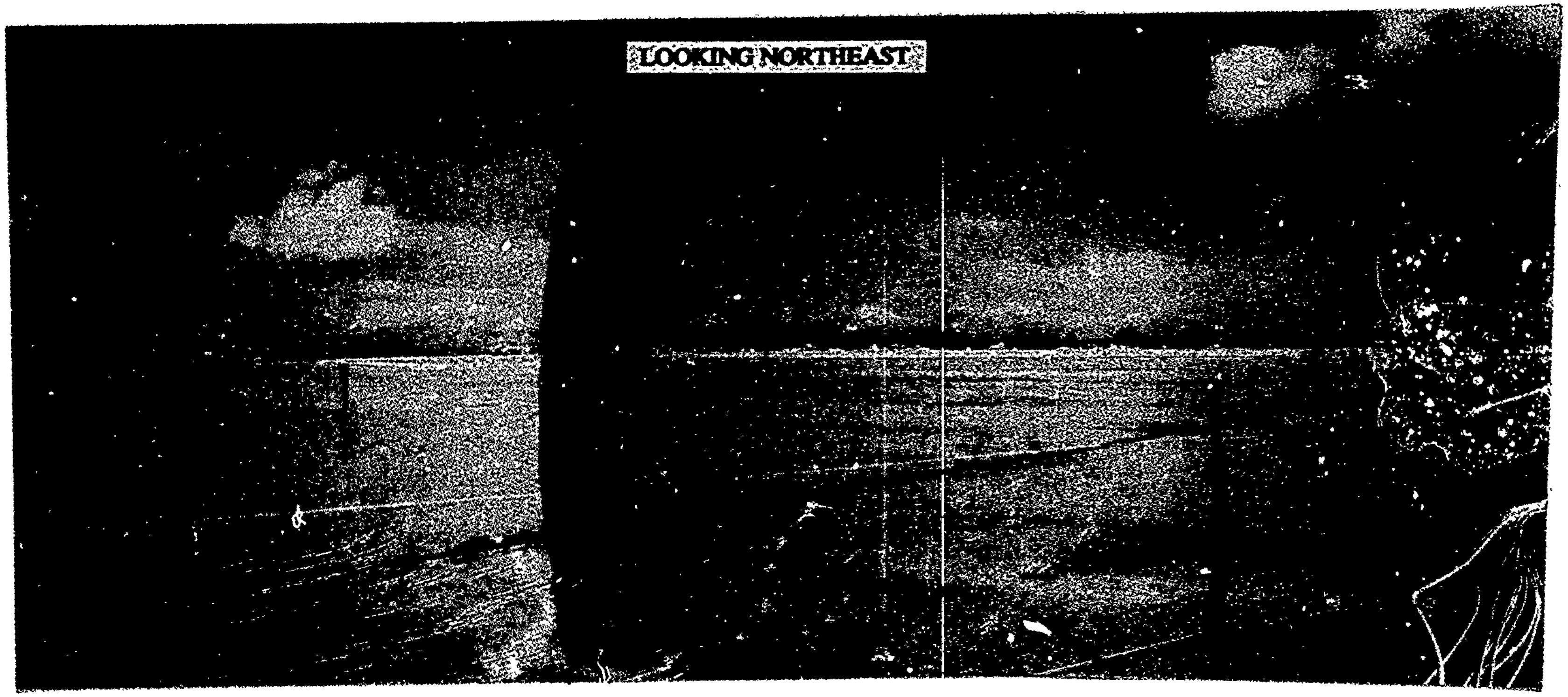


Figure II-6 Cont'd.

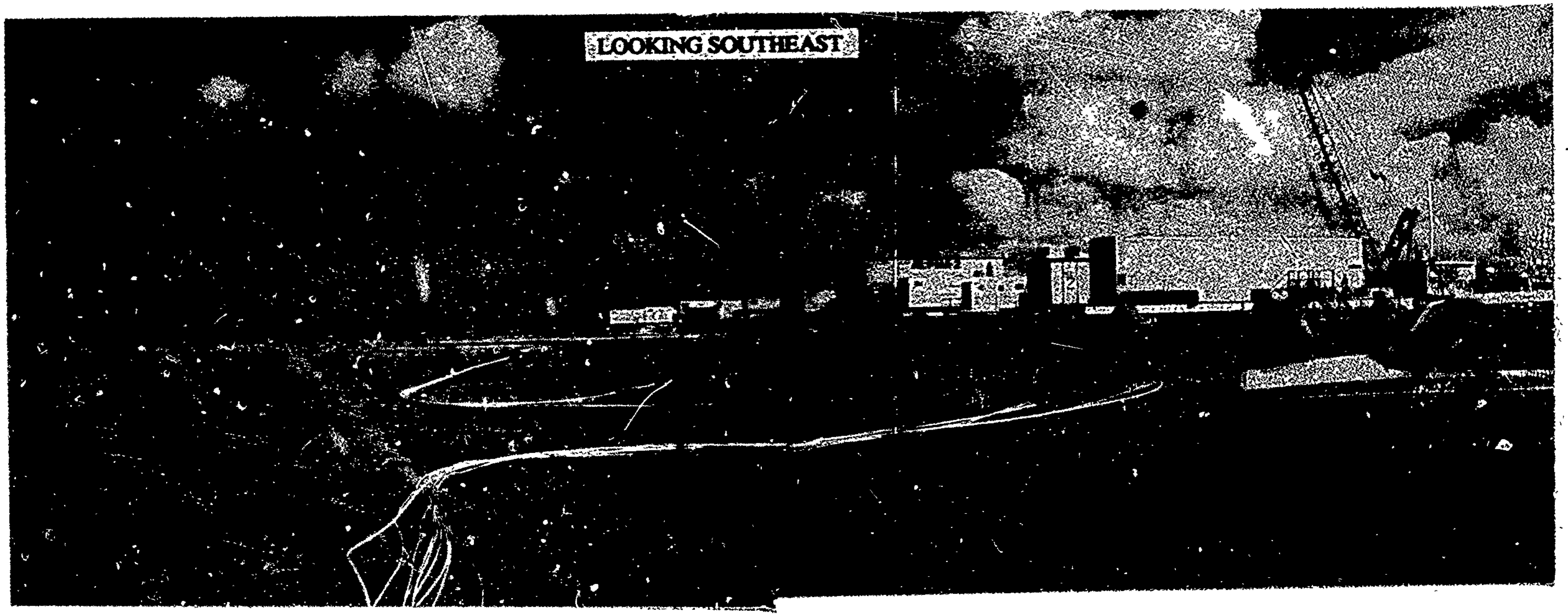


Figure II-6 (Cont'd.)

Figure 6 (Cont'd.)

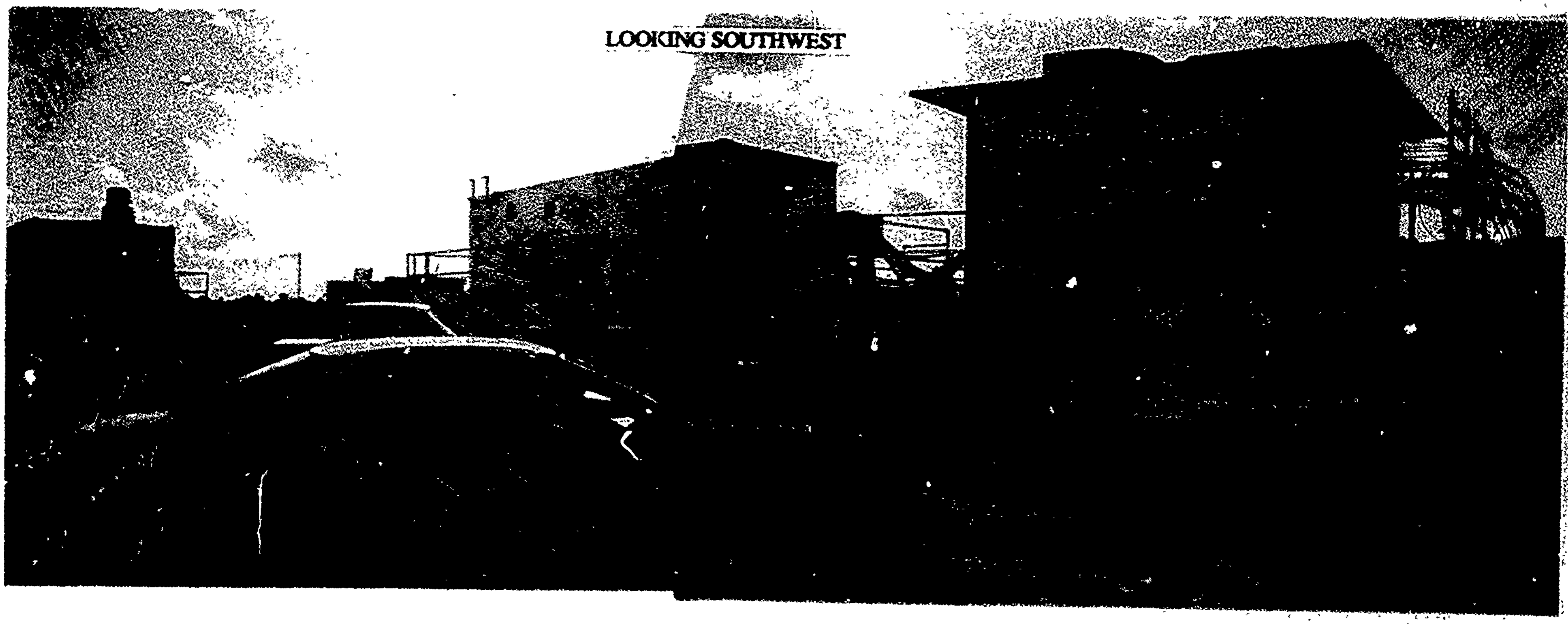


Figure II-6 (Cont'd.)

Figure II-6 (Cont'd.)

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FIGURE II-7 GROUND PANORAMIC FROM BEYOND GZ TOWARD INSTRUMENTATION AREA, PRE-DETONATION

Looking South from the Northeastern edge of the site, this panoramic view documents the position of the target at GZ and the line of instrumentation trailers at the Southern edge of the BEXAR scar. Of particular note is the lack of equipment at GZ (other than a guard vehicle). These images provide excellent information about the texture of the soil around and at GZ, the significant amount of trackage from both wheeled and tracked equipment. A crane can be seen, well off the site and situated behind the two story temporary building. The entire trailer configuration is present in these images. Note also the two sets of portable floodlights still erected south of the GZ.

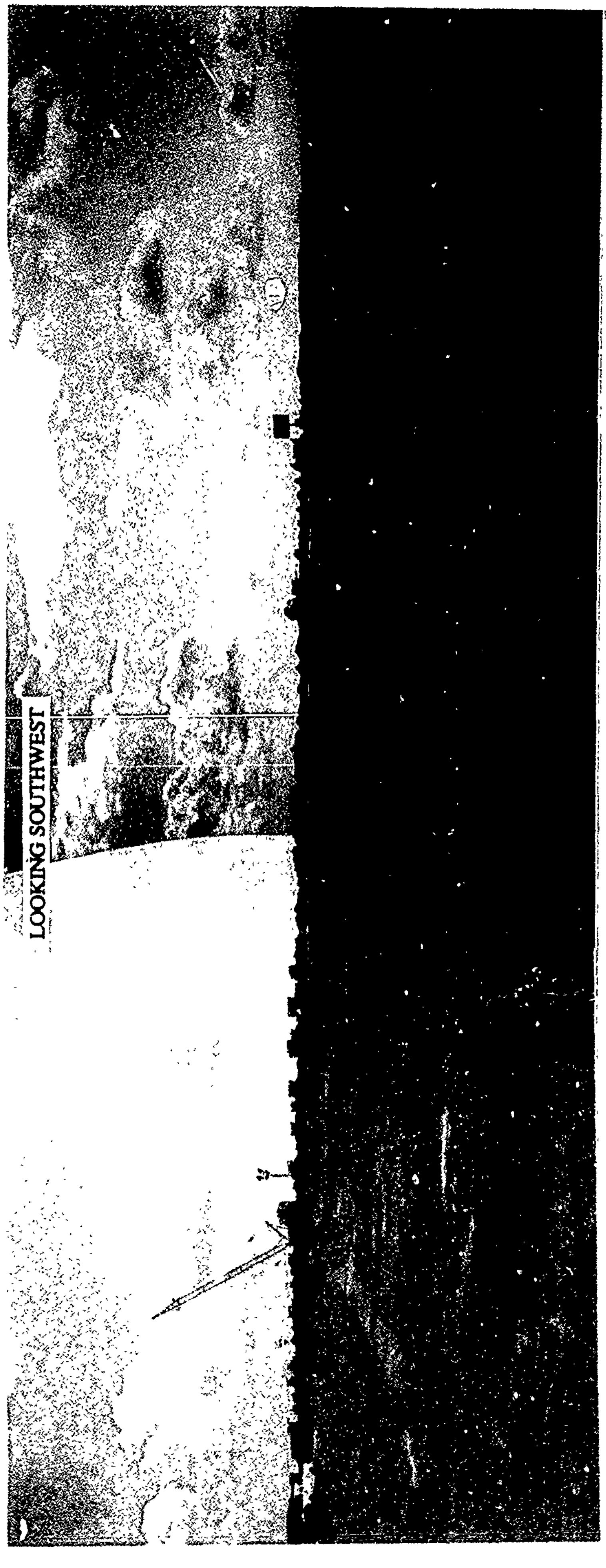


Figure II-7

FIGURE II-8 AERIAL VIDEO, 6 SECONDS BEFORE DETONATION

This image depicts an overall view of the test area. The complete lack of activity indicates that the test is imminent. There is no equipment in the GZ area or the open storage area. There are no vehicles anywhere on the site or surrounding roads. A small amount of water remains in the artificial ponds. Everything is completely "buttoned up". The weather appears optimum with no clouds or cloud shadows visible over the test area.

Figure II-8

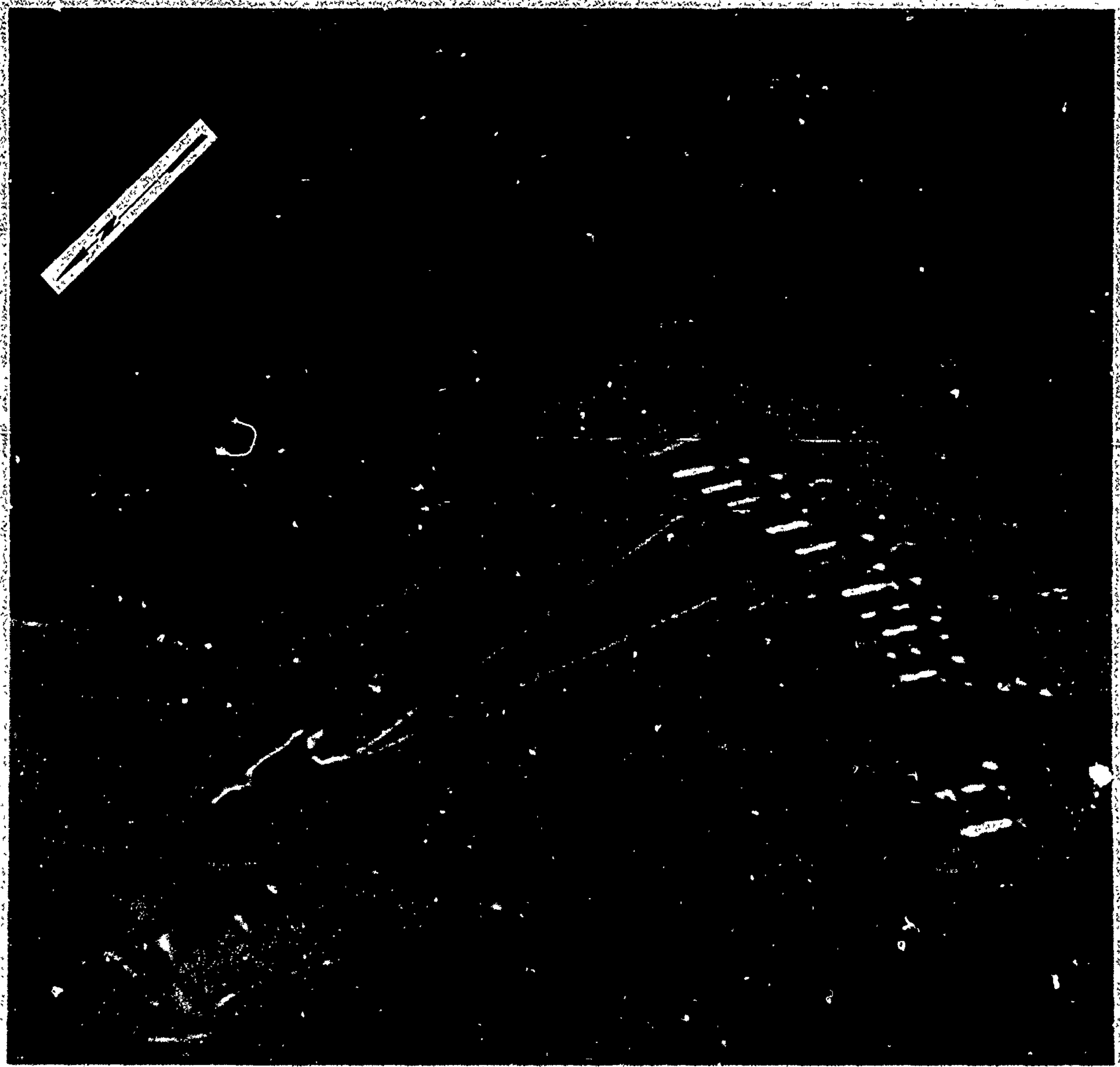


FIGURE II-9 GROUND VIEW FROM GZ-1, 1 SECOND BEFORE DETONATION

This image is from a hard mounted ground camera station to the southeast of GZ (GZ-1) and is overlooking the short, sparse vegetation surrounding the site. The GZ appears near the center of the image and is depicted by an elevated square target. The target is divided into quarters with the upper right and lower left quarters painted black, and the upper right and lower left quarters painted white. The window in the upper right corner of the main photograph provides simultaneous coverage of the recording from an attached seismograph. Note that the seismograph reading is steady and shows no unusual seismic activity. The time, in seconds form Time Zero (TZ), is depicted just below the seismograph recording. The other annotations document the distance in feet and the azimuth of the camera from GZ. The thin parallel lines traversing across the entire image are electrical power lines that stretch between the camera and the target site. These can be used as indicators for changes that may occur during the seismic activity created by the test.

Figure II-9

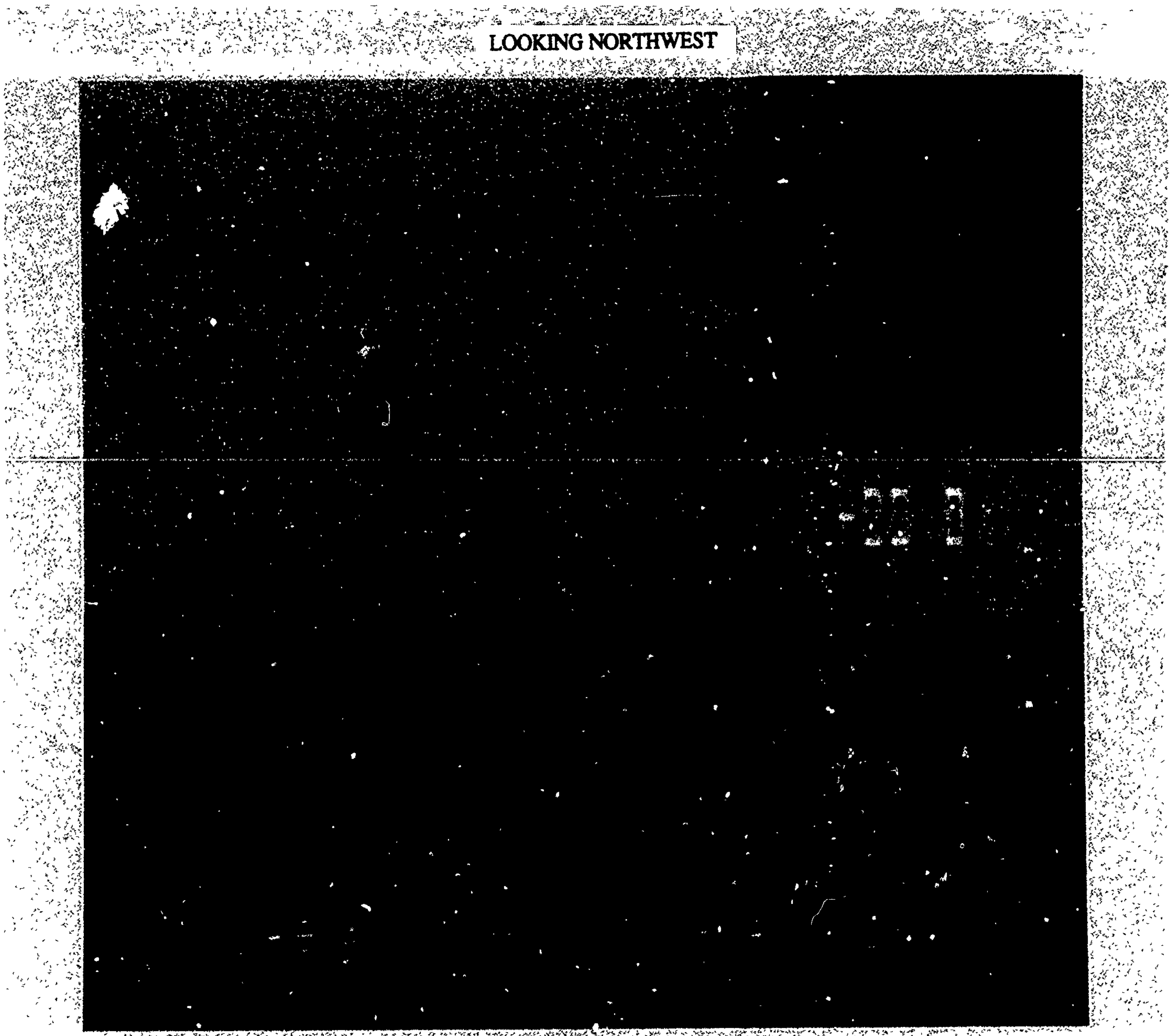
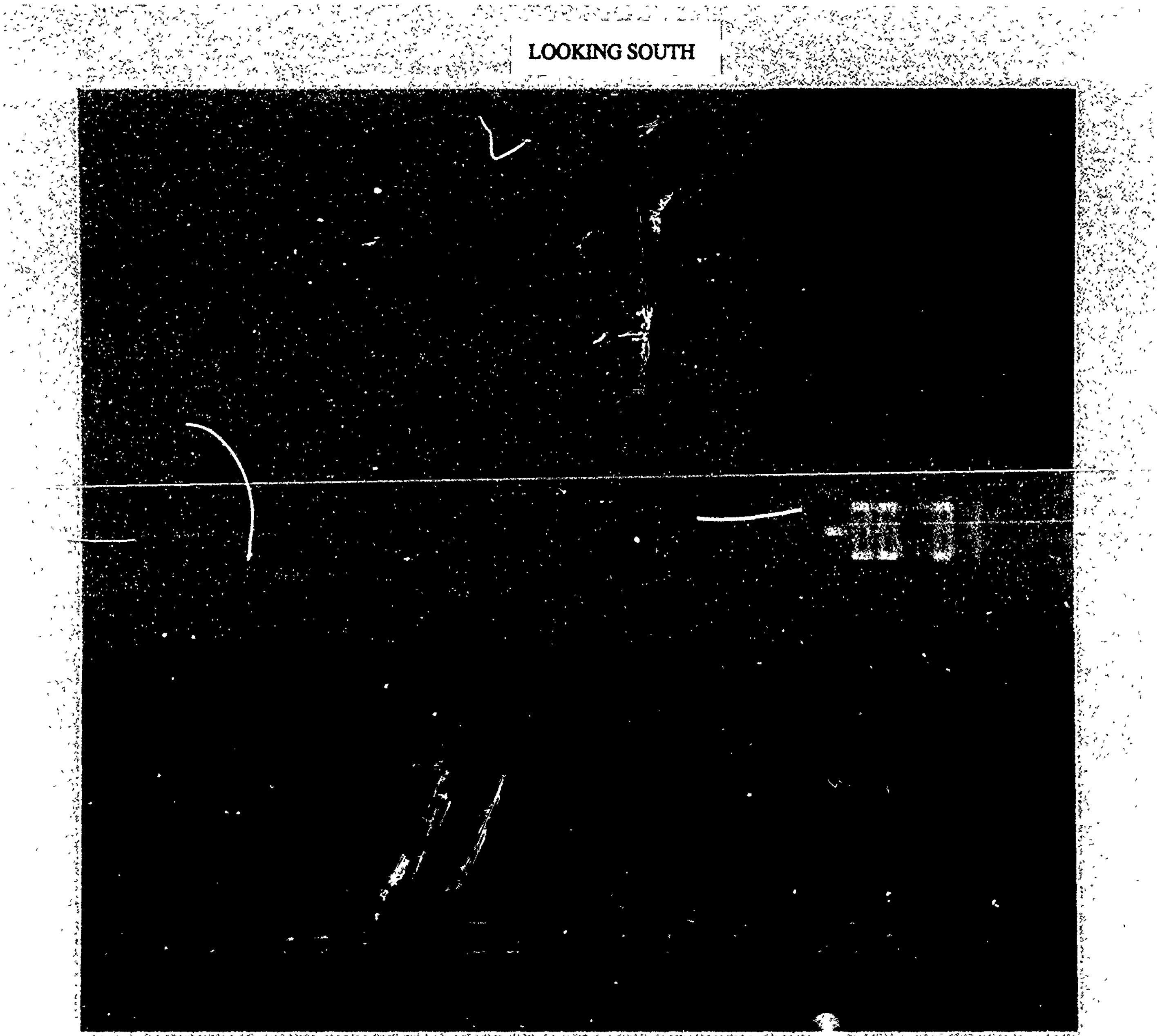


FIGURE II-10 GROUND VIEW FROM GZ-2, 1 SECONDS BEFORE DETONATION

This GZ-2 image was acquired from a hard mounted ground camera station positioned to the north of GZ., at approximately three times the distance form the GZ as is GZ-1. The camera is at an elevated point and is looking over an area of low vegetation, through a cleared area, to the GZ. The raised target over GZ can barely be discerned at the crest of a small rise, as two light and two dark spots below and to the left of the center of the photograph. The seismometer needle is steady and shows no seismic activity at this time. The time from Time Zero (TZ) is documented below the seismometer window, and the camera station distance and azimuth from GZ is depicted near the bottom of the photograph.

Figure II-10



1.1 DETONATION

FIGURE II-11 AERIAL VIDEO TEST AT TIME OF DETONATION

This image was acquired within a second after detonation, prior to the generation of the dust cloud, but depicting the initial surface changes at the GZ. Most noticeable is the drastic spectral change in the ground within the cleared area to the north and northeast of GZ. These linear, light colored streaks appear to be caused by expansion breaks in the surface covering of the test area, exposing different soil materials. Cracks and breaks throughout the test area can be discerned by this spectral change. Some of the changes, for example near the line of trailers, appear to originate and expand from smaller light colored areas noticeable on photographic coverage prior to the detonation. It also appears that there is a general lightening of the ground surface, implying that a subtle textural change has occurred on the surface.

Also noticeable is the fact that the water in the two ponds has changed color, possibly due to motion stirring up debris that had settled to the bottom of the ponds since their inception. No noticeable collapse crater, or indications of venting can be observed, and no extensive damage to the site is evident.

Figure II-11

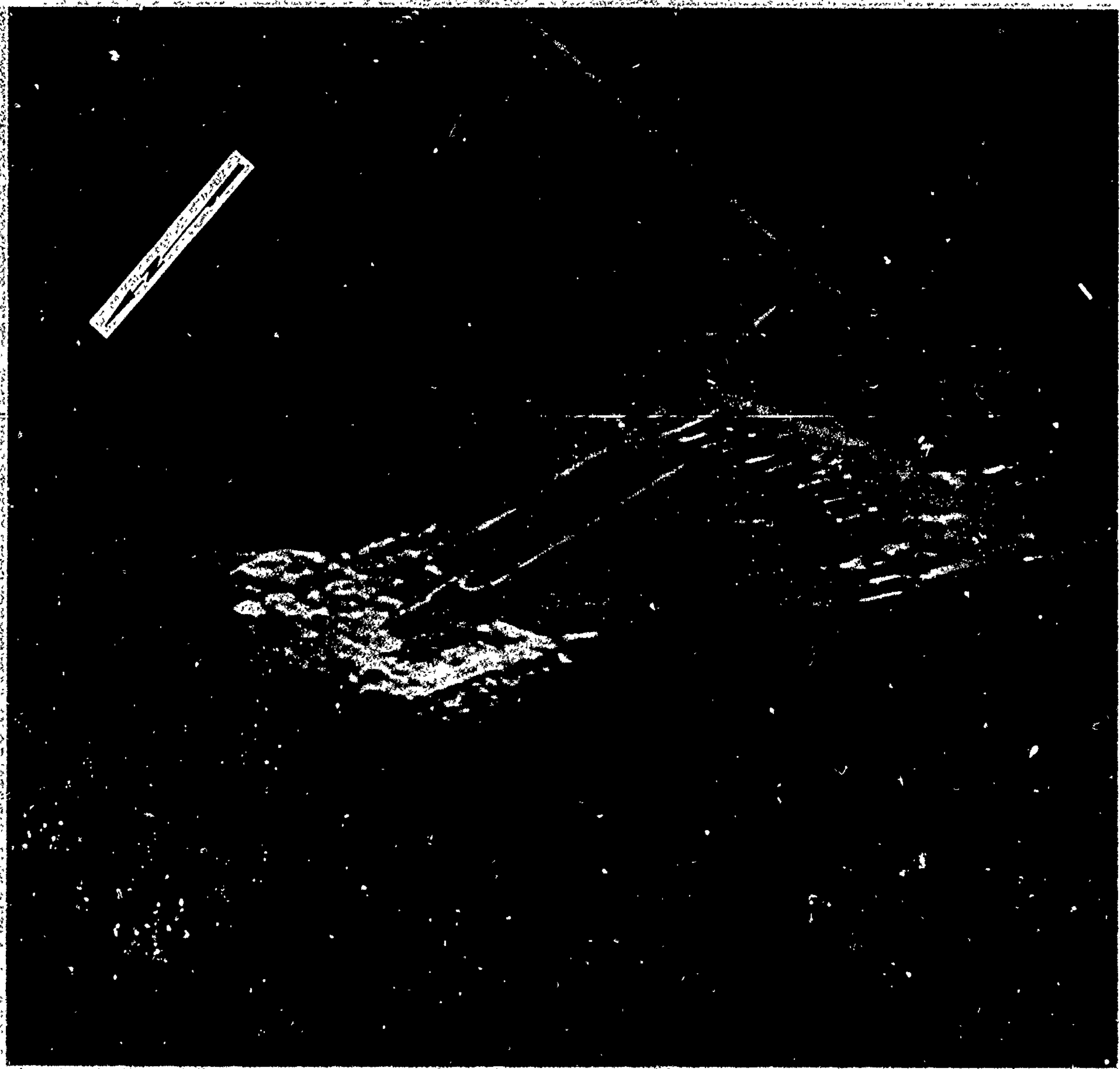


FIGURE II-12 GROUND VIEW FROM GZ-1 AT TIME OF DETONATION

This photo was acquired at the time of detonation, as evidenced by the registration of the initial seismic shock in the image of the seismograph, and the clock data. At this time the target over GZ remains standing and there is no evidence of dust or debris emanating from the test area. However, by using the power lines that cross the image as a rough grating system, a significant change in the relative height of the GZ becomes apparent. Cursory measurements from the bottom of the photograph to the top most powerline observed in the image indicates that neither the camera nor the powerlines have changed position relative to one another, yet the test target now appears to be in line with the top powerline, whereas on a previous photo (FIGURE II-9) the target is well below the top powerline. This indicates that there has been a significant change in the height of the GZ. No other changes are evident either on the terrain or in the air above the detonation point.

Figure II-12

LOOKING NORTHWEST

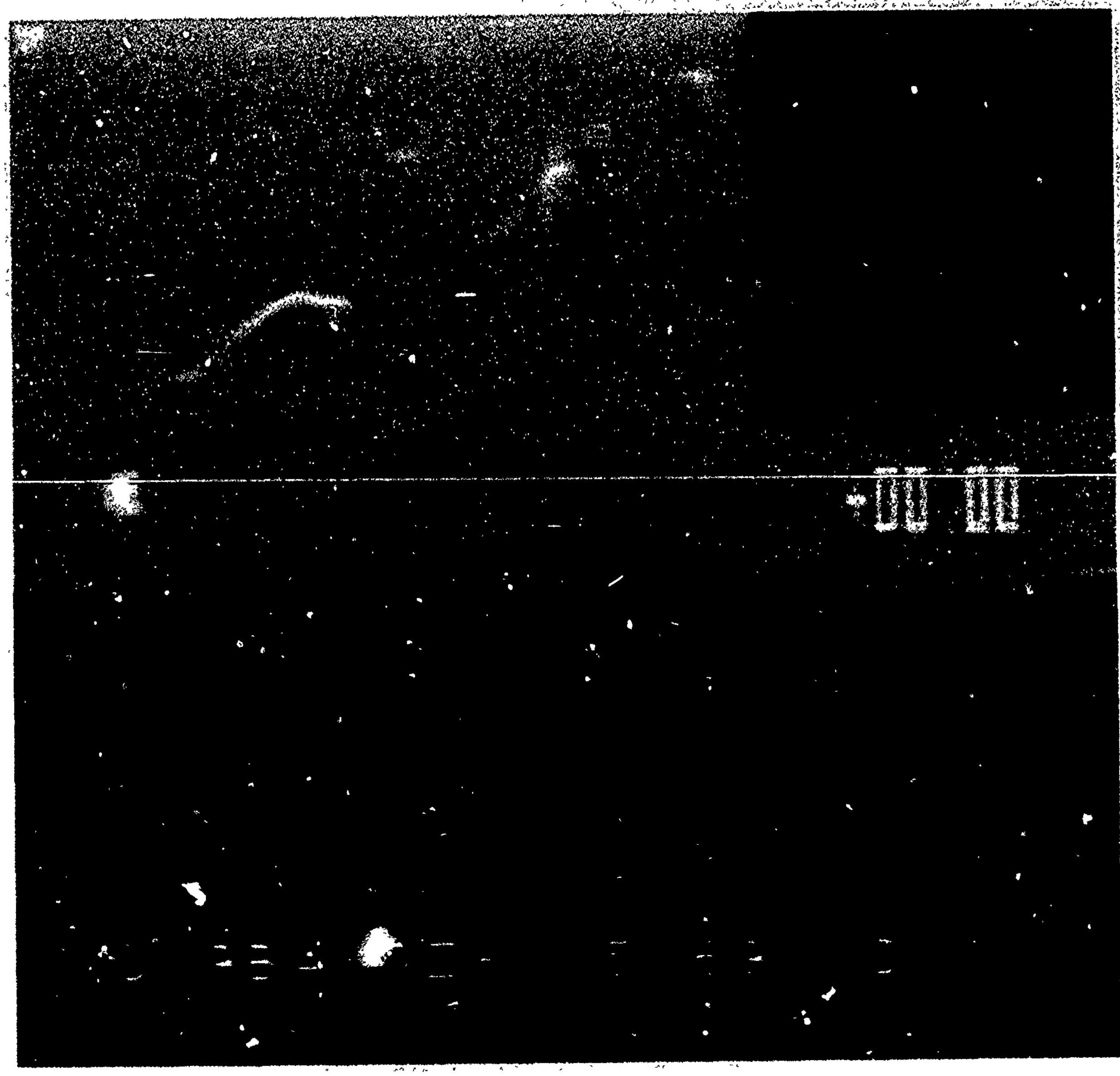
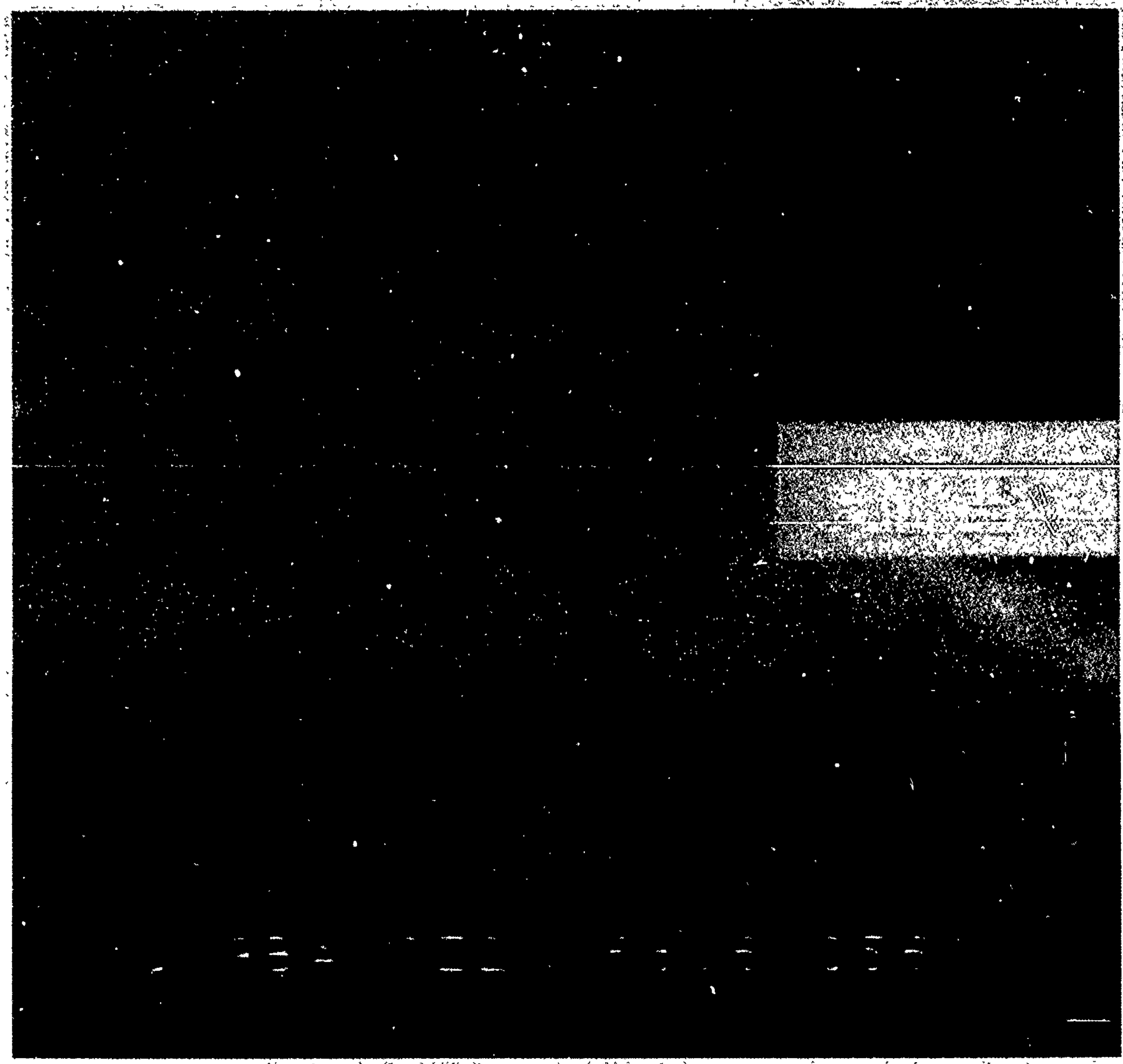


FIGURE II-13 GROUND VIEW FROM GZ-2, 25 SECONDS AFTER DETONATION

This image shows the condition of the test area twenty-five seconds after the first seismic shock from the detonation. The strength of the continuous shocks is depicted by the violent swings of the stylus of the seismometer, documented in the right corner of the photograph. The camera is still vibrating from the initial shock and has swung to its left (east), and upward from its previous position. The GZ is completely covered by a dust cloud and dust continues to rise from the open areas surrounding the test site. The GZ target cannot be observed. There appears to be no evidence of vegetation damage such as fallen or stripped trees or branches.

Figure II-13

LOOKING SOUTH



1.2 POST DETONATION

FIGURE II-14 AERIAL VIDEO OF GZ AFTER THE TEST DETONATION

This image shows little change from the image taken during detonation; although the dust cloud has dissipated and seismic activity has ceased. Some additional scarring has taken place to the northeast of GZ and the spectral signal has changed over the pond area. However, no noticeable change can be discerned in the pattern of the cable bundles or in the trailer area. No obvious breaks or faults can be observed in the open areas or across roads and trails. There appears to be no structural damage to the vegetation, although there is a hint of a spectral change in the vegetation to the north of the site. This is possibly due to the deposition of dust from the dust cloud.

Figure II-14

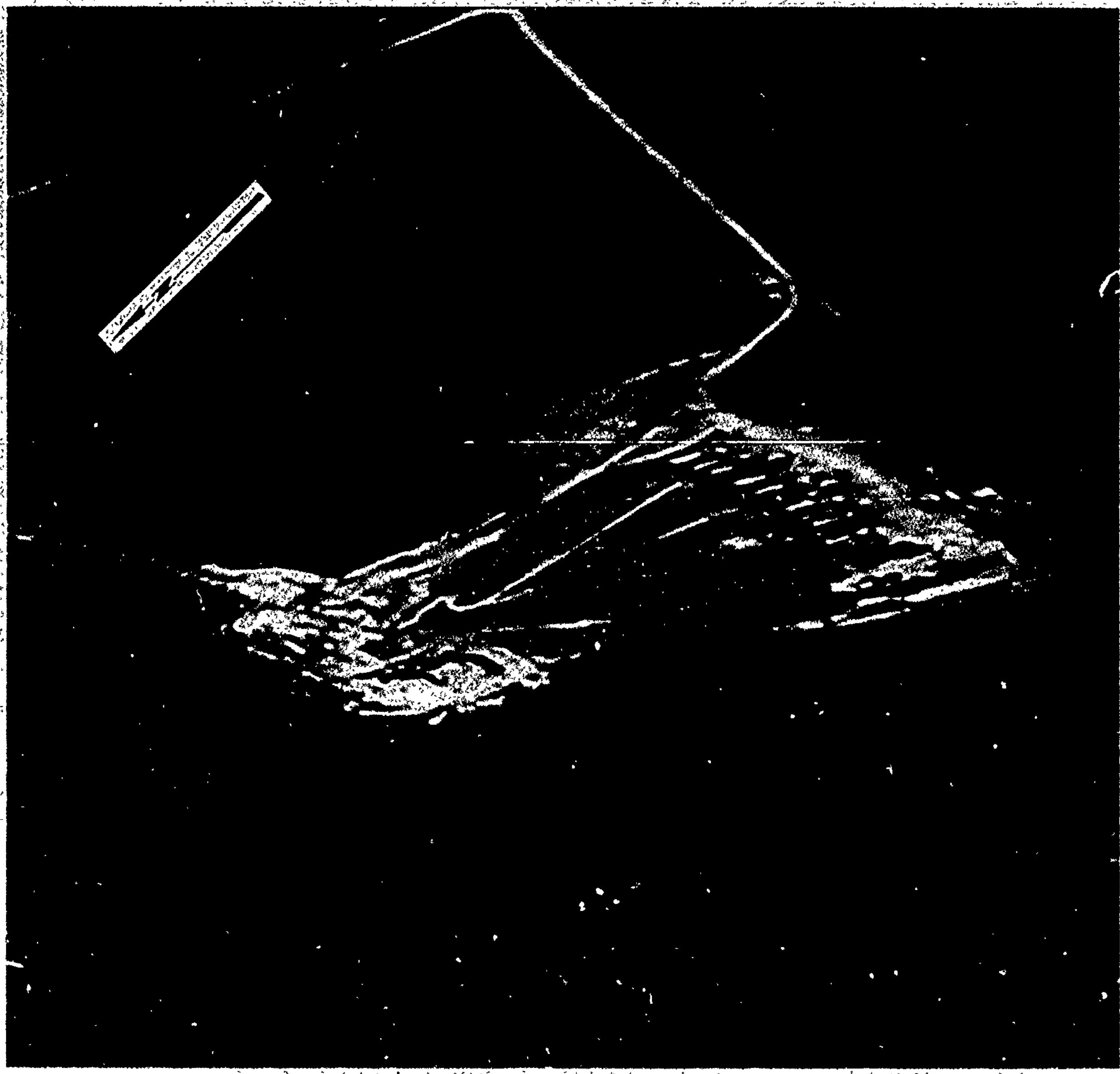


FIGURE II-15 GROUND PANORAMIC (360°) FROM INSTRUMENTATION AREA, POST-DETONATION

These images were taken from the southwestern corner of the test site the day after the detonation. Limited change has taken place due to test effects throughout the site. All the instrumentation trailers and open sites appear undamaged, although some slight misalignment and level changes resulted from the crushing of the honeycomb vibration isolators separating the trailers from their hardened mounts. The bundles of cables do not appear to be damaged or misaligned and none show any evidence of breakage or being soil covered. A pile of rocks near the Simulator - 3 trailer has changed position due to seismic movement, and the light wooden vehicle barricades have been toppled. The greatest change to be noted is in the texture of the bare ground surrounding the trailers and throughout the test site. The initial smooth compacted surface of the area is now rutted, and the soil has been broken into clumps, networked by small irregular shallow cracks. It appears that the small grained compacted soil that covered the surface prior to detonation has disappeared either as dust or has been broken into the clumps of soil now visible.

The number of vehicles now in the area and the presence of a functioning derrick at the southeastern portion of the site area indications that the test has occurred. Recovering the diagnostic data and the removal of equipment has begun. Since no equipment is at the GZ, the recovery of that data and possible drilling awaits the lifting of further safety precautions.

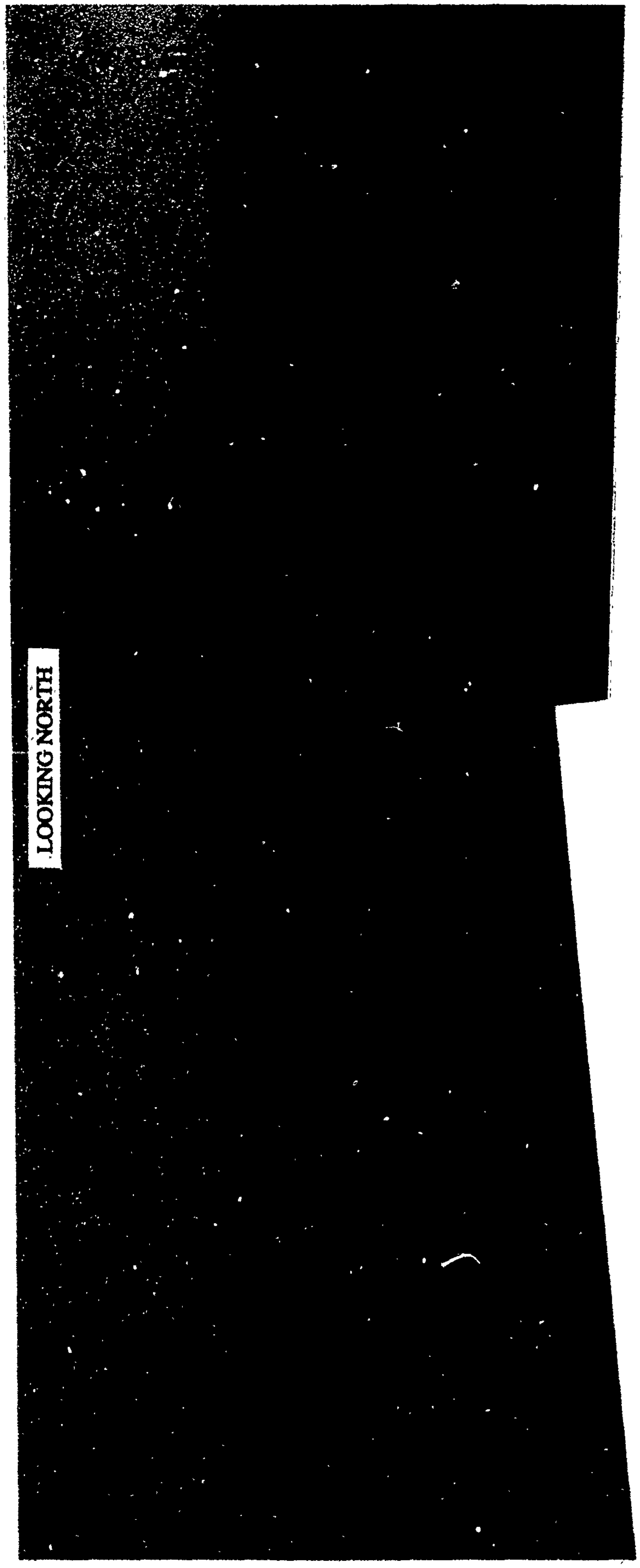


Figure II-15

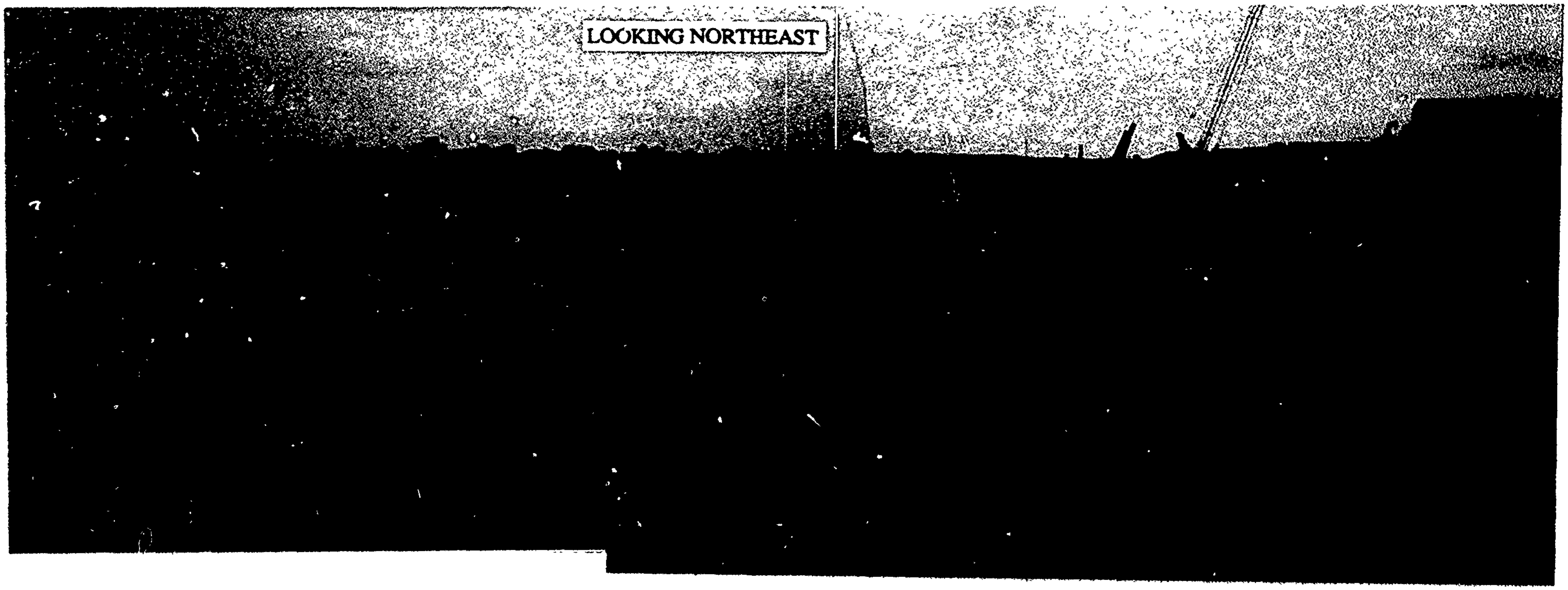


Figure II-15 (Cont'd.)

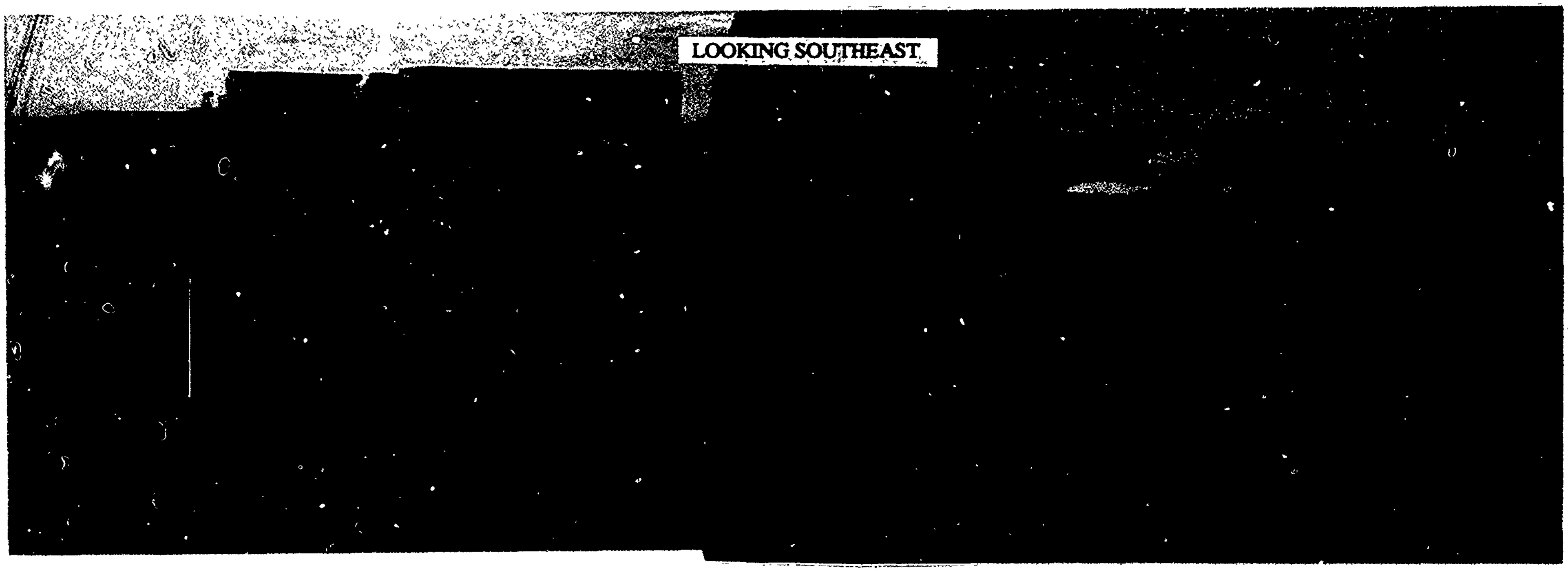


Figure II-15 (Cont'd.)

Figure 5 (Cont'd.)

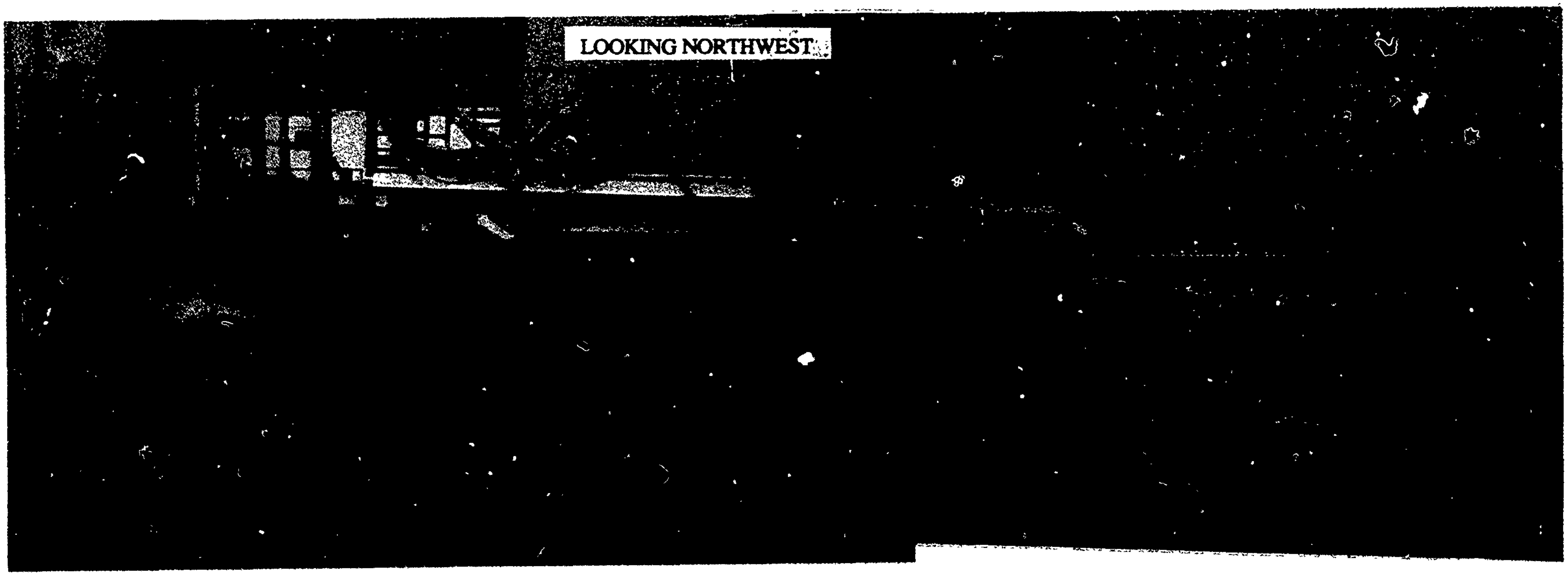


Figure II-15 (Cont'd.)

2.0 GROUND ZERO

FIGURE II-16 AERIAL VIDEO OF GZ, POST-DETONATION

This image shows that the cable configuration has retained its generic shape, although the kinks and turns appear more exaggerated than in pre-detonation images. Several shallow circumferential cracks are evident in the image. Patches of the original compacted surface soil can be seen separated by rougher textured soil that underlays the initial surface. The least disturbed material is in the rectangular areas at the terminus of the cable bundles. The site remains devoid of activity at this time.

Figure II-16

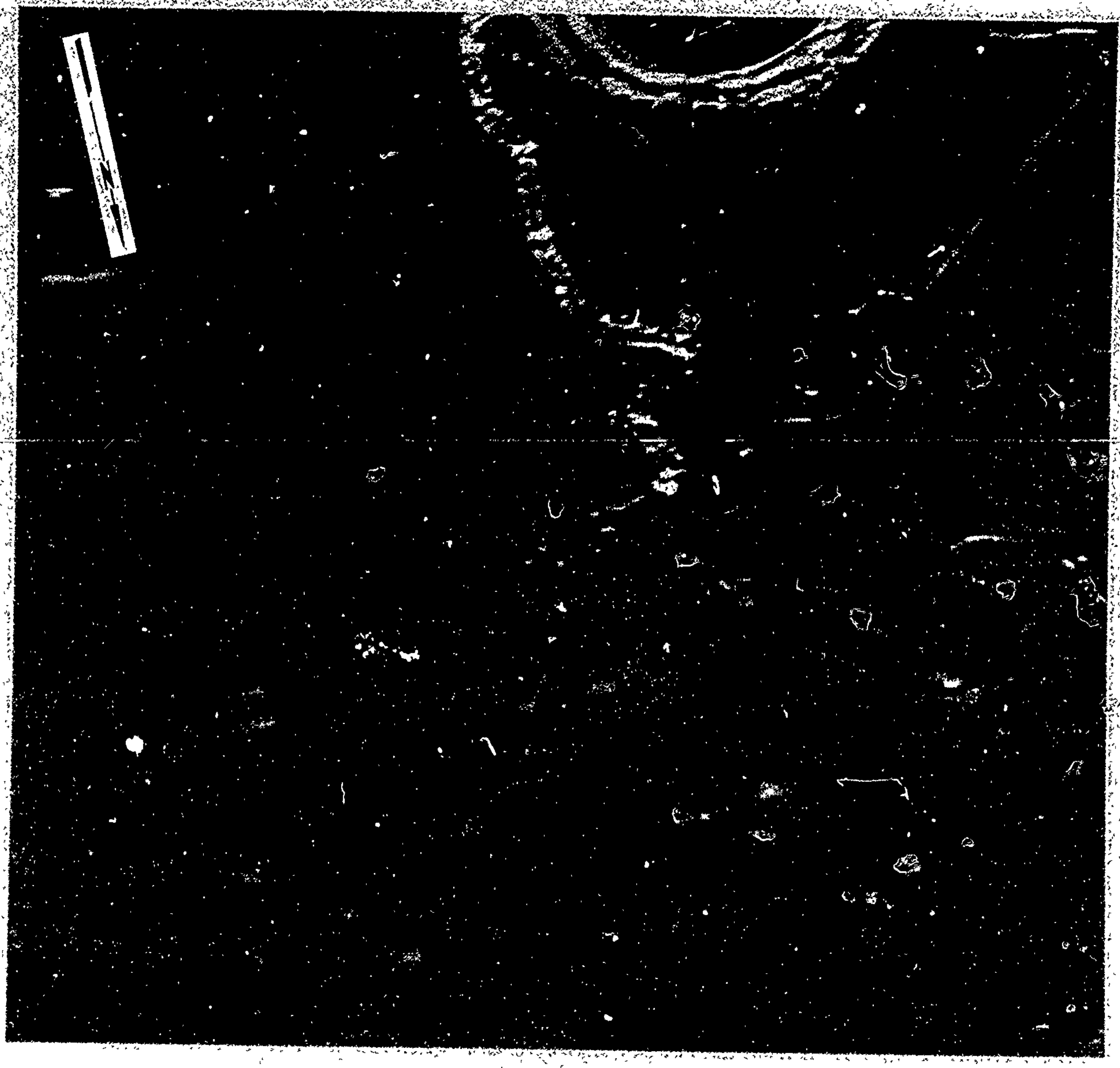
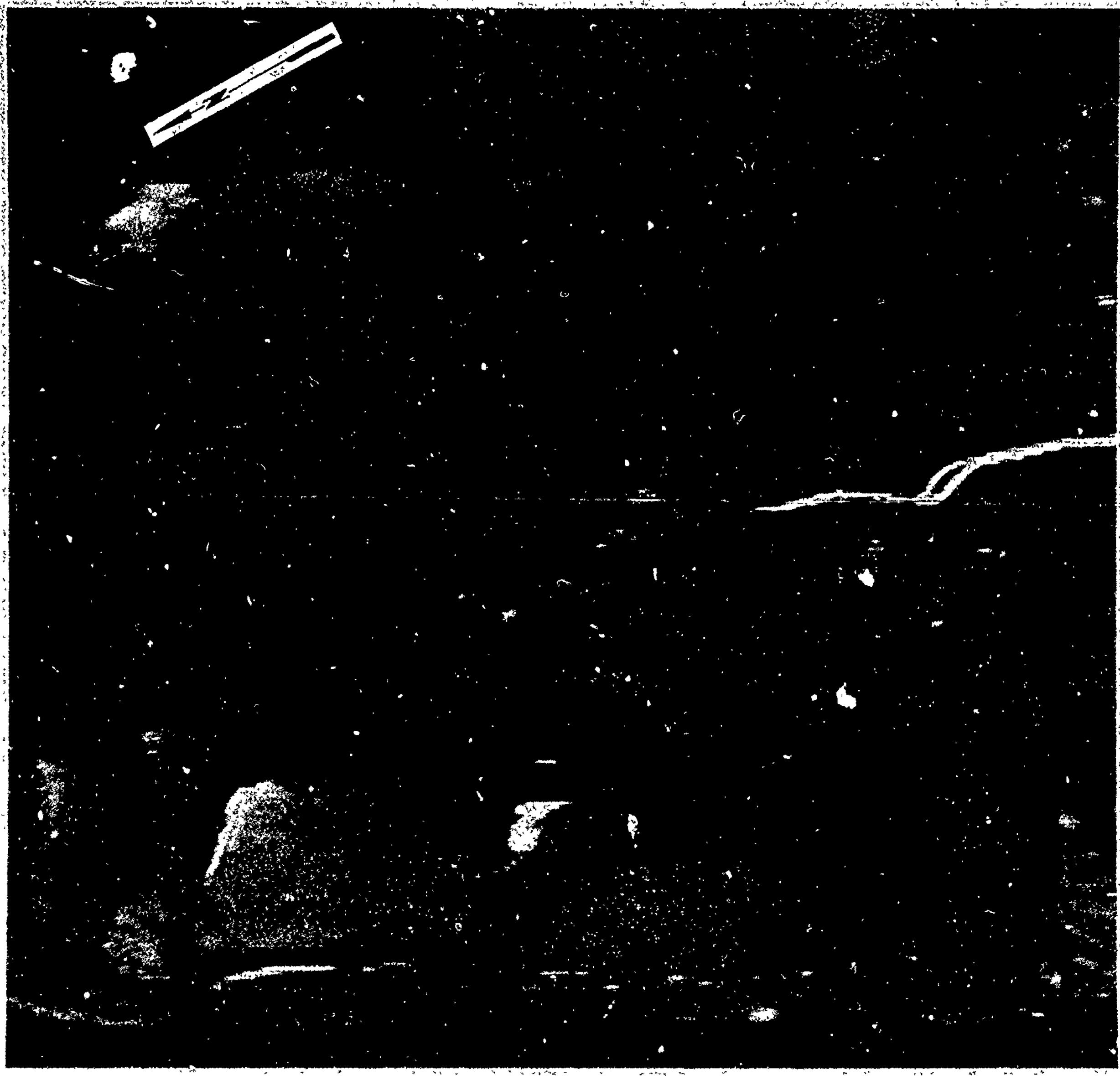


FIGURE II-17 AERIAL VIDEO OF GZ AND PONDS, POST-DETONATION

A cursory comparison between pre- and post-detonation images of the pond area indicates that the water level in the pond has not changed, and that no damage to the berms or changes in alignment is evident. The pond water appears cloudy, indicating that the disturbed bottom sediment has yet to settle out of the water. Shallow radial cracks and patches of rough textured soil can be differentiated from the remaining patches of the initial compacted surface soil.

Figure II-17



3.0 CRACKS

FIGURE II-18 AERIAL VIDEO OF CRACKS, POST-DETONATION

This image depicts the surface terrain to the north and west of GZ. Both radial and circumferential shallow cracks can be observed within the area. The difference between the initial compacted dirt surface and the rougher textured underlying soil is easily discerned. The evergreen vegetation to the northeast of the GZ does not show any damage and does not appear to be heavily covered by dust or debris. In fact if dust settled on the vegetation and its surrounds, it is very light and would, in a short time, be easily dissipated by the prevailing winds.

Figure II-18

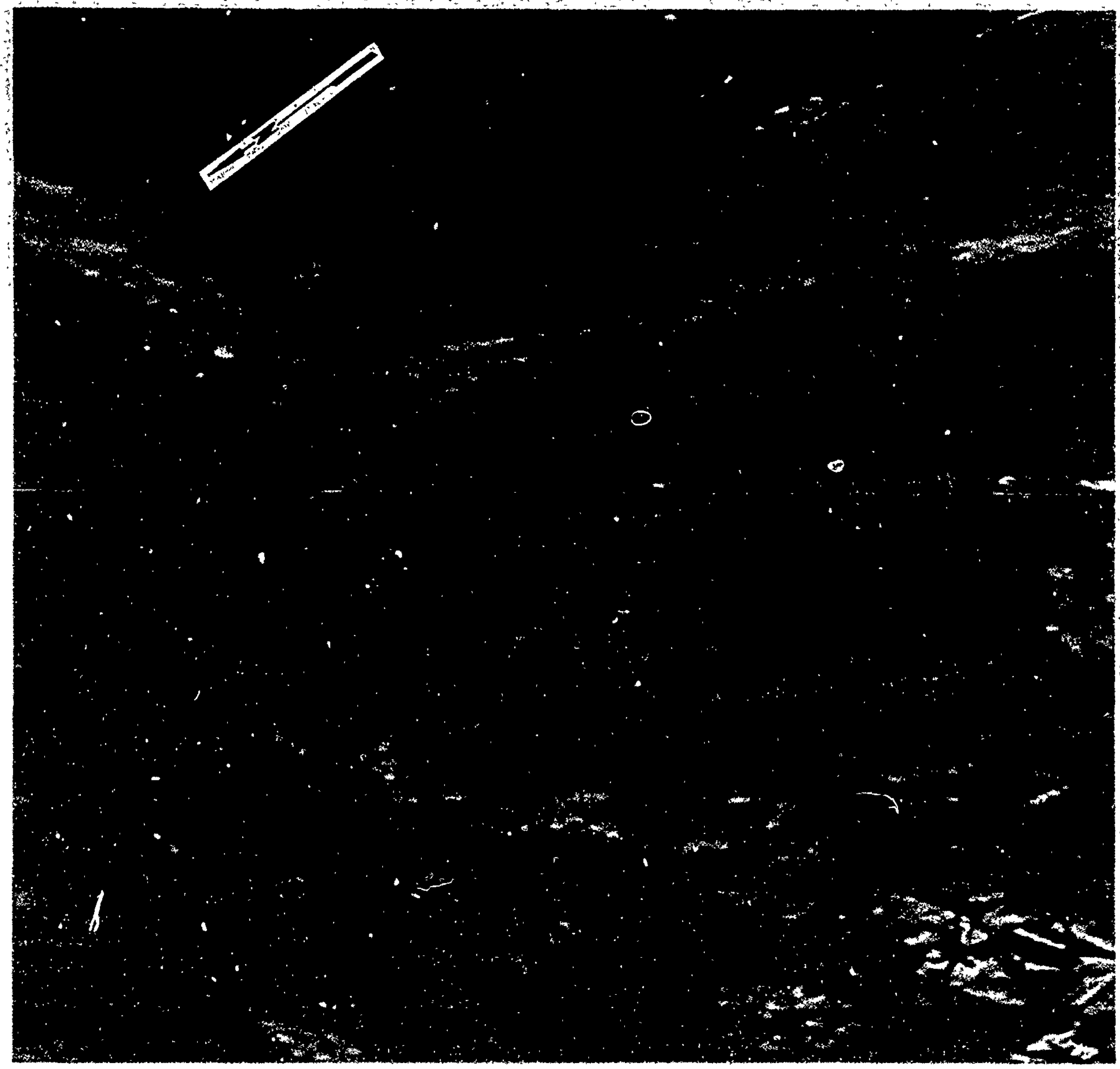


FIGURE II-19 AERIAL VIDEO OF CRACKS, POST-DETONATION

This image depicts the area to the east-northeast of the GZ. Both radial and circumferential shallow cracks can be observed as well as the difference between the original compacted soil and the less homogeneous underlying soil. The vegetation adjacent to the test area shows no damage or accumulation of dust or debris.

Figure II-19

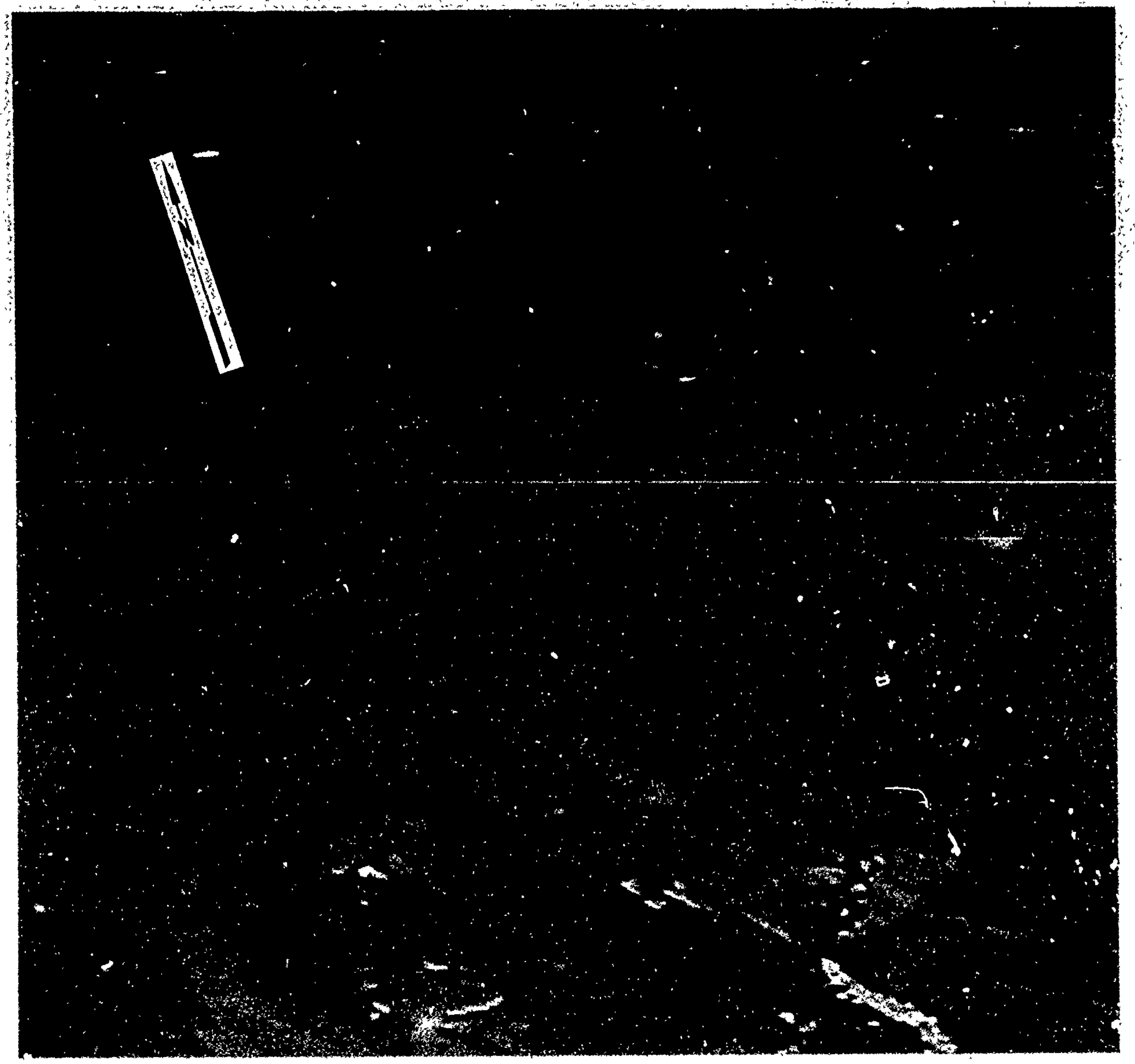


FIGURE II-20 CLOSE-UP VIEW OF GROUND INSTRUMENTATION AREA, PRE-DETONATION

The first two images of the ground surface near the trailer area, taken prior to the detonation, depict the homogeneity of the soil texture, and its sponge-like characteristics evidenced by the footprints in the images. The fine grained material does not appear to be similar to the coarser textured surrounding soil and may be the spoil from the drill site. The spectral characteristics of this soil should differ from that of the surrounding area.

Figure II-20

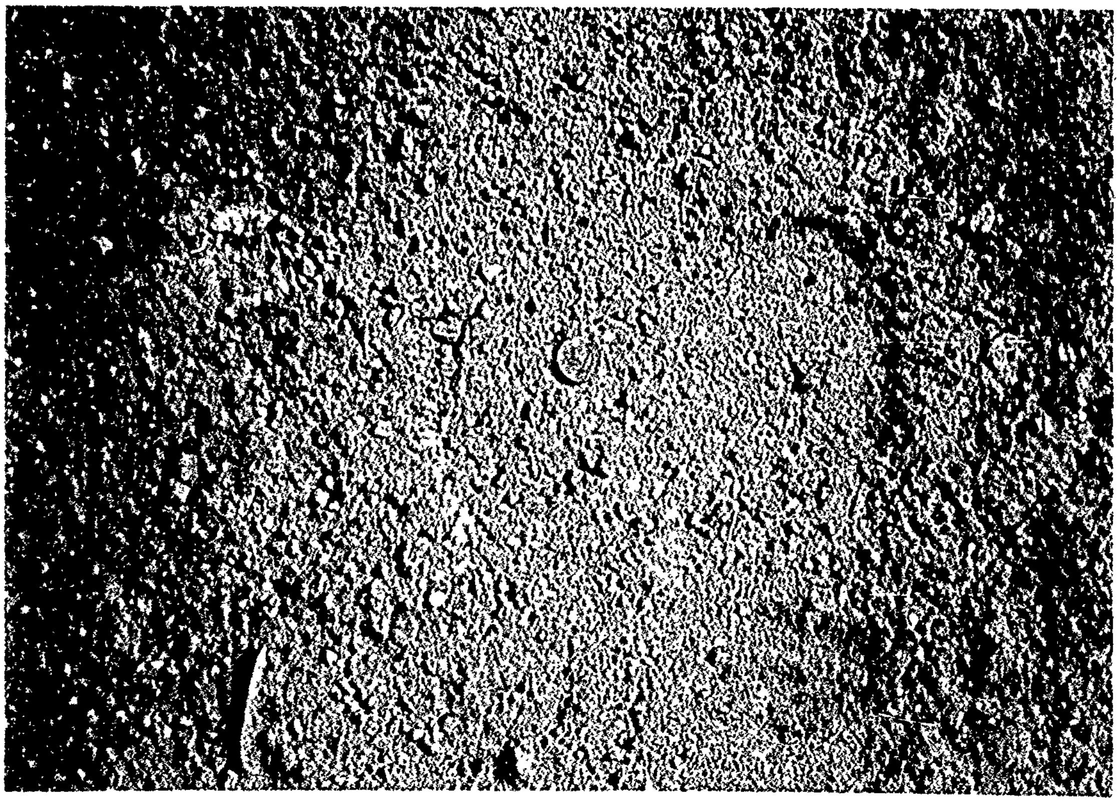
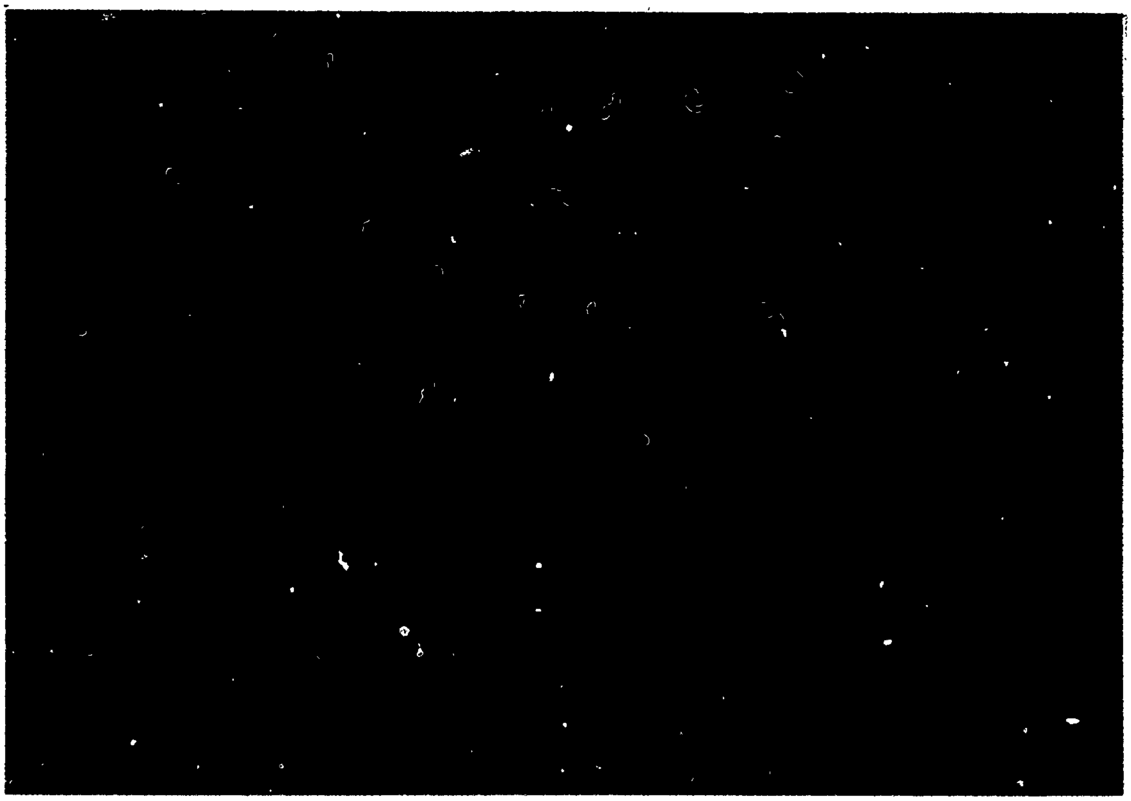


FIGURE II-21 CLOSE-UP VIEW OF GROUND AT INSTRUMENTATION AREA, POST-DETONATION

The next three images were taken after the test detonation, and documents the surface changes that have occurred due to the seismic movements of the underground blast. A comparison with the other close views of the soil before the test indicates that some of the fine grained material has disappeared and the coarser textured compacted underlying soil is now visible. An irregular network of shallow cracks is evident breaking up the compacted "crust" of the surface material, but not fracturing individual rocks or pebbles. Few macro-changes have occurred, although there is some indication of mounding near the GZ, and the GZ target is not visible. The underlying soil does appear to have the same, but slightly darker, color as the initial top-soil.

Figure II-21



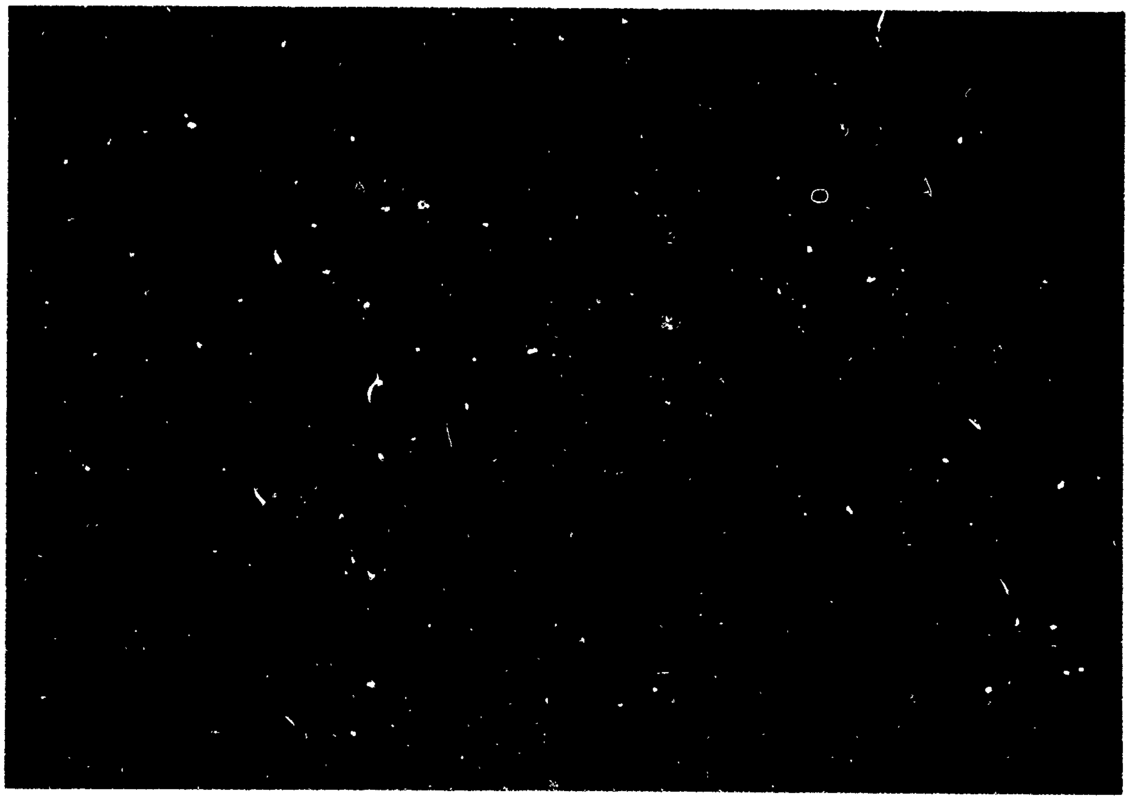


Figure II-21 (Cont'd.)

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4.O DEBRIS CLOUD

FIGURE II-22 AERIAL VIDEO OF DEBRIS CLOUD SECONDS AFTER DETONATION

This image was taken seconds after the test detonation and depicts the origin of the debris cloud as being to the north of GZ along the edge of the abutment that was left when the test site was initially cleared and leveled. Note that the water in the ponds is still seeking its original level. Little or no dust can be seen rising from the area around the trailers, or between the trailers and the GZ. The debris cloud slowly drifted to the north of the site and was totally clear of the area four minutes after the detonation. Its effect on the vegetation to the north of the site was minimal but may be sufficient to change the spectral signal of the vegetation for a short time. Prevailing winds, snow or rain will eventually clear the vegetation of the clinging dust thereby limiting the time when the spectral change can be observed.

Figure II-22

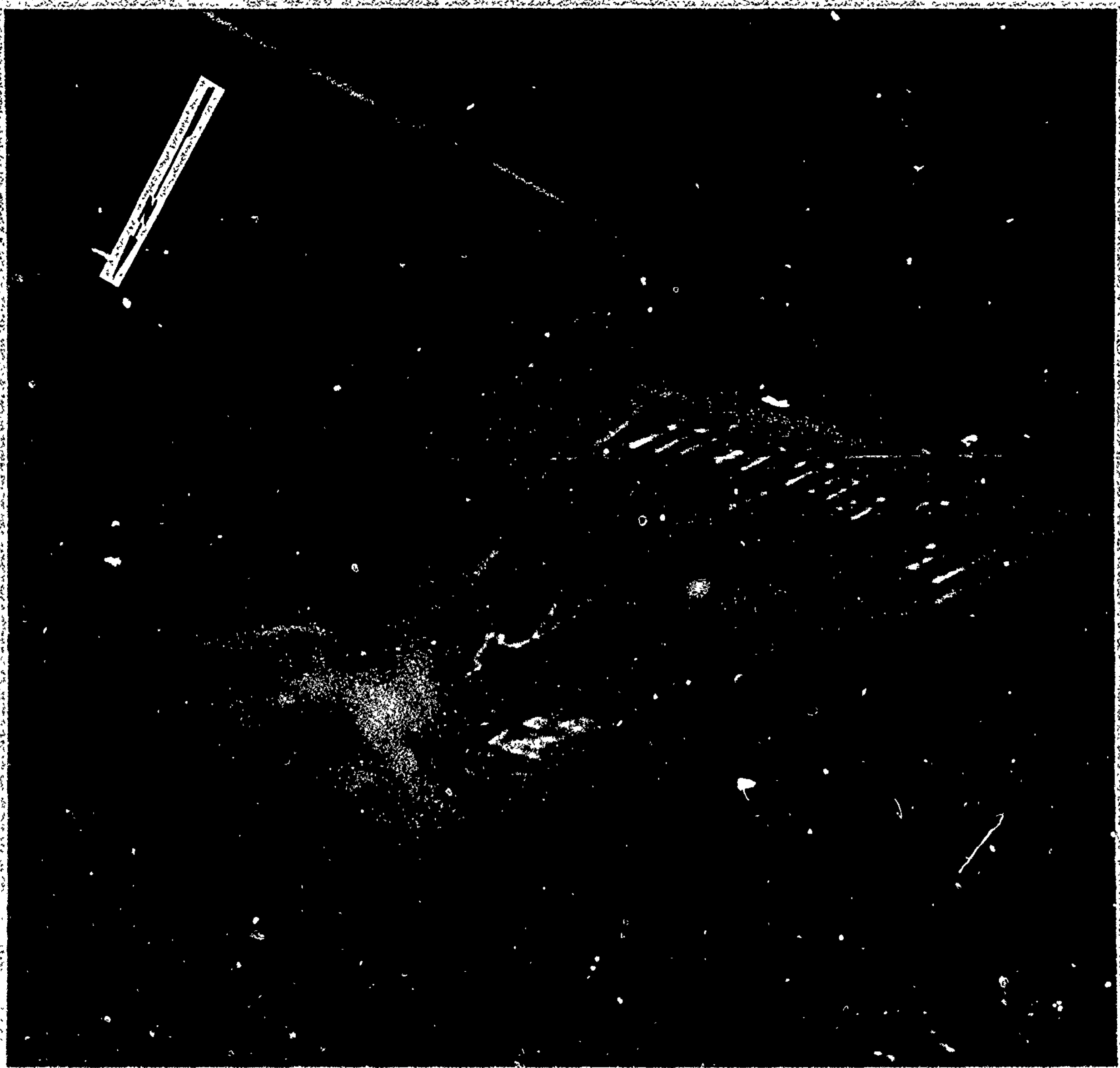

FIGURE II-23 GROUND VIEW OF DEBRIS CLOUD FROM GZ-1

This image was taken from the GZ-1 ground camera 20 seconds after the test detonation. The seismic recorder is showing continuous and significant seismic action. Debris completely obscures the test site and a light accumulation of dust has begun to settle over the surrounding vegetation but does not reach the vicinity of the ground camera station. Most of the debris is moving to the north of the test site.

Figure II-23

LOOKING NORTHWEST

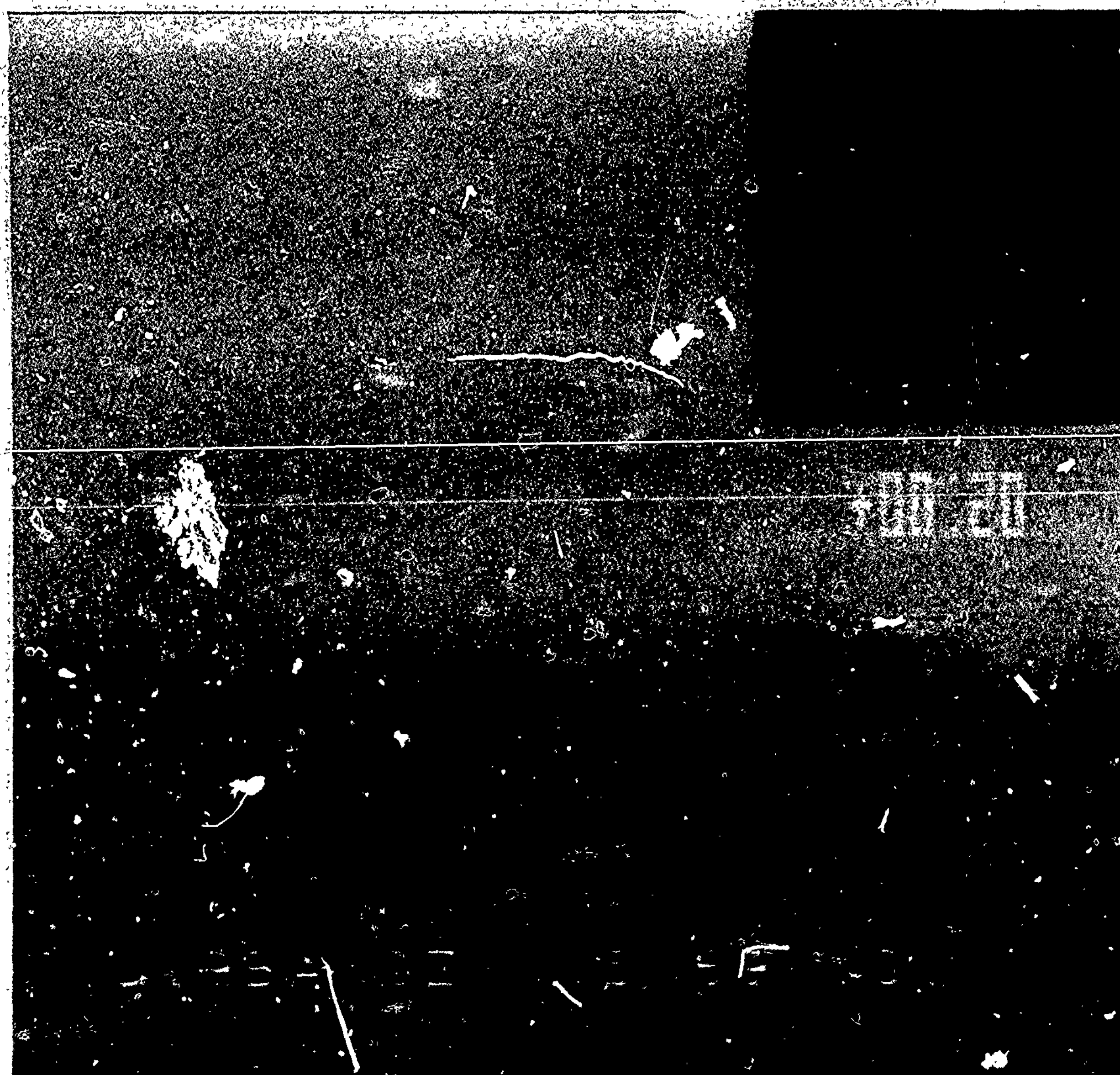

FIGURE II-24 GROUND VIEW OF DEBRIS CLOUD FROM GZ-2

45 seconds after the detonation, the seismic recorder is still indicating severe seismic activity at the GZ camera station. The debris cloud is near its maximum height and intensity. It has begun to settle on the surrounding vegetation covering the full extent of the camera's view. Some dust appears to be still rising from the area of the abutment at the northern edge of the test site.

Figure II-24